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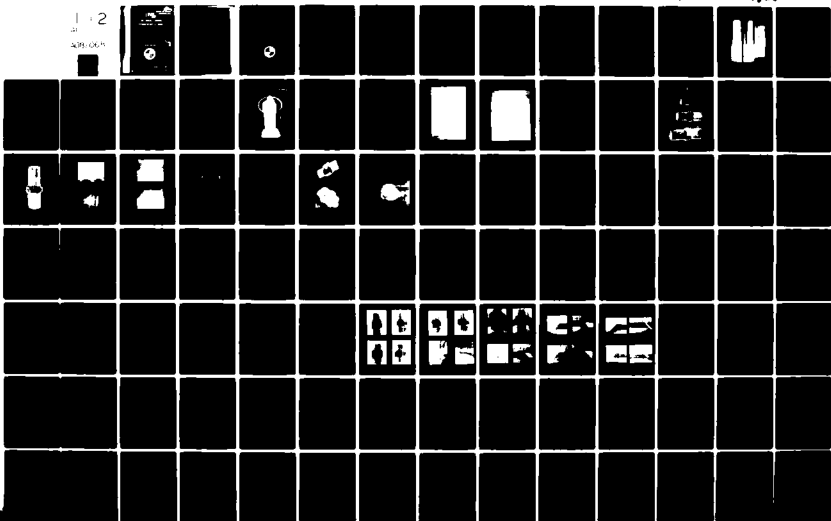

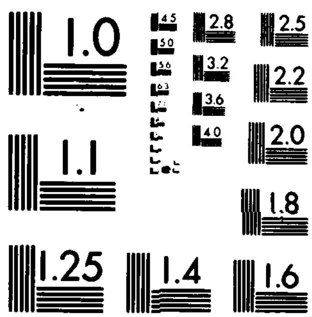

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

REPORT NO. MT-053
NOVEMBER 1979

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EXPLOSIVELY JOINING DISSIMILAR METAL TUBES

A PROJECT OF THE
MANUFACTURING TECHNOLOGY PROGRAM
NAVAL SEA SYSTEMS COMMAND

FINAL REPORT

NAVAL ORDNANCE STATION
LOUISVILLE, KENTUCKY 40214

ABSTRACT

This is the final report of a project to further develop the explosive cladding of dissimilar metals and to use this process by joining pipes or tubes of metals that cannot be welded by conventional methods. The work was conducted at the Naval Ordnance Station, Louisville, Kentucky (NAVORDSTALOU), with some testing performed by a commercial testing laboratory. The original plan of this project was to utilize a "scarf-joint" method developed during initial explosive cladding studies at NAVORDSTALOU. This plan was shelved when visits to the Naval Ships Engineering Center presented a greater need for a fitting to penetrate an aluminum watertight bulkhead or deck with a pipe of a different metal. This is the path followed after discussions with shipyard personnel disclosed the magnitude of the problem, especially in the Surface Effect Ship (SES) program.

This report covers development of a basic penetration fitting design and the testing required to have it accepted as a candidate ship part produced by non-conventional processes, Also covered is the qualification of explosives used in the process. Various metal combinations were clad in sizes from .750" to 6.0" diameter. Inspection for defects was conducted using ultrasonics and dye penetrant. Salt spray, shear, and fatigue testing were also a part of this project.

FOREWORD

This is the final report on work completed under Naval Sea Systems Command (NAVSEASYSCOM) (SEA-05R2) Work Requests 76-WR-64105 and 76-WR-62460 to develop a process of explosively joining metal tubes of dissimilar metals and to perform an evaluation of the bonded area by non-destructive and destructive studies. The work was performed by the Manufacturing Technology Department of the Naval Ordnance Station, Louisville, Kentucky. Funding was provided by the Ship Systems Research and Technology Office (SEA-05R2) of NAVSEASYSCOM under the Manufacturing Technology Program (MTP).

This Manufacturing Technology Report has been reviewed and is approved.

Thad Peake

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SECTION 1

INTRODUCTION

A major problem associated with ship construction is being able to maintain watertight integrity, or to seal off various sections of the ship. Normally, this is accomplished by fitting all openings with gaskets and a means to tighten the closure to insure against leakage. When the bulkhead or deck must be penetrated by wires or piping, a more serious problem is encountered. For most wiring, a separate "stuffing tube" must be used for each wire (or each encapsulated assembly). When a pipe of a metal similar to the construction type is used, it is a simple matter to cut a hole, insert the pipe, and weld it into position. The watertightness problem arises when a penetration is made with a pipe of dissimilar type metal (one that cannot be welded into place by conventional methods). In this case, there are two methods used by most shipbuilders. For small pipes and tubing, a stuffing tube similar to the one for wire is used. A flange and gasket method is used for larger sizes. Neither of these methods are ideal because of difficulty obtaining a good seal, keeping the nuts from vibrating loose, and the amount of space required for each flange.

This project originated with the development of joining dissimilar metal tubes using the explosives cladding process. The method developed by Naval Ordnance Station, Louisville, Kentucky (NAVORDSTALOU), used a scarf-joint (Figure 1) where the more ductile metal is normally clad to the less ductile (e.g., aluminum to steel). This "transition joint" was to be used where a pipe or tube of a non-corrosive and non-sparking metal was desired in a specific area, but not required elsewhere. This approach was shelved when visits to Naval Ship Engineering Center showed a more urgent need for a method of penetrating a watertight aluminum bulkhead or deck with a dissimilar metal pipe such as stainless steel. From this point, work centered on explosive cladding, machining, and testing a penetration fitting where there is only a narrow collar of one metal clad to a short section of a dissimilar metal.

SECTION 2

TECHNICAL APPROACH

2.1 THE PROBLEM

There is a continuous problem in maintaining "watertight integrity" on all seagoing ships. This problem is amplified in U. S. Navy ships by frequent changes in operational stresses, which are caused by shifts in modes of cruising (peacetime to battle simulation, etc.).

The area of the watertight integrity problem addressed in this project deals with bulkhead and deck penetrations, principally by pipes and/or tubes of a metal different than the bulkhead or deck is made of. There are two methods of penetrating a watertight bulkhead or deck by a pipe of a dissimilar type metal; using a stuffing tube similar to that used for electrical wiring, and with a flange and gasket arrangement. The stuffing tube method is used for pipes and tubes up to four inches. The flange type is used for larger pipes and some of the smaller sizes.

Some of the basic faults of the stuffing tube are: (1) finding a stuffing material with flexibility to form around the pipe, but will not ooze out around the gland nut; (2) one that will not harden or deteriorate within a couple years; and (3) having to periodically check for tightness of the nut. The flanged penetration has many problem areas, such as: (1) the bulkhead or deck area needed is large in comparison to the pipe size, e.g., a seven inch diameter is needed for a two inch pipe; (2) at least four additional holes are needed for bolts; (3) the bolt body is not insulated from the bulkhead (dissimilar) metal; (4) the nuts can vibrate loose, even the plastic inserted type; (5) access to both sides of the bulkhead is necessary if the nuts need tightening and two men are required to do the job; and (6) there is the ever present galvanic corrosion found whenever dissimilar metals are used together in a salty atmosphere.

2.2 PRELIMINARY DISCUSSIONS

The project started with meetings between Naval Ordnance Station, Louisville, Kentucky (NAVORDSTALOU), personnel and Naval Ship Engineering Center's (NAVSEC) Engineering Materials and Services Office, Washington, D. C. The purpose was to acquaint NAVSEC personnel with established explosive cladding developments and advantages in joining dissimilar metals, present the NAVORDSTALOU designed transition joint, and to obtain information as to where this item could best be utilized. A variety of samples showing the different metals that could be joined by explosive cladding were shown and discussed.

NAVSEC program managers were very receptive to the explosive cladding concept. They did not, however, think the scarf-joint pipe transition joint (Figure 1) had sufficient application aboard most Navy ships. Primary importance was given to penetrating watertight bulkheads and decks of the all aluminum construction Surface Effect Ships (SES). While the basic SES is constructed of aluminum, the piping is made of other type metals for strength and resistance to various corrosive elements.

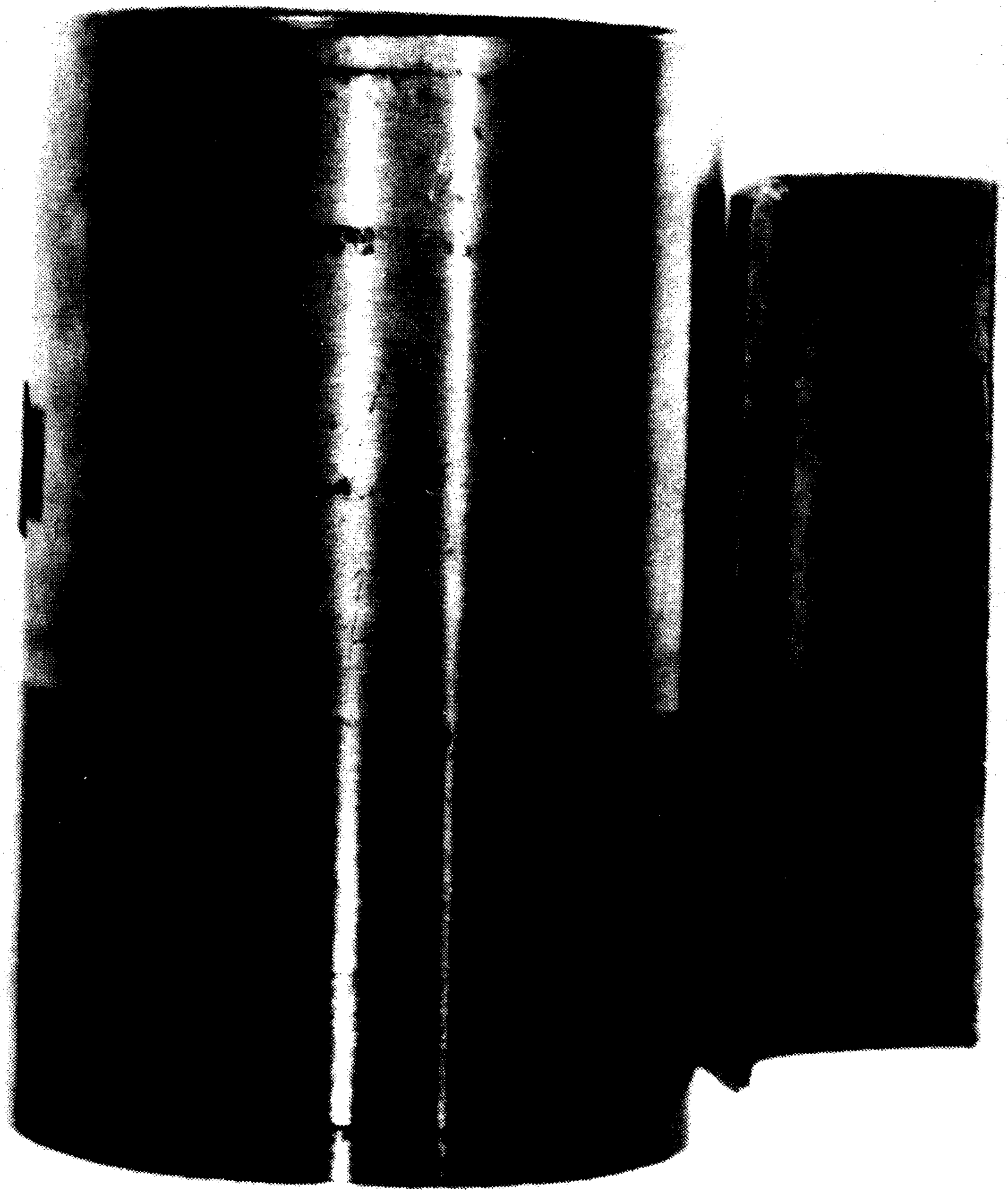

FIGURE 1 SCARF-JOINT PIPE TRANSITION JOINT

The scarf-joint transition joint (Figure 1) is an earlier development at NAVORDSTALOU. The typical use for this part is where there is a need for one type metal in a specific environment and a different type in an adjoining compartment. The part is unique by giving a smooth coupling with both pipes having the same inside and outside dimensions.

While the scarf-joint did not appear suitable for penetration of watertight bulkheads, it was not discarded as a candidate for other uses. NAVORDSTALOU was requested to pursue the development of a penetration fitting that could be used on any type ship and using a variety of alloys with emphasis on aluminum and stainless steel.

2.3 DEVELOPMENT SHOTS

Basic parameters for explosively cladding plates of most common metals are well establihsed. To obtain the best clad strengths, the materials have to be brought together at an angle, velocity, and impact pressure sufficient to cause a high velocity jet to be formed, "wipe" the meeting surfaces clean of contaminants, and force the liquified surfaces to weld together (Figure 2). These conditions have been determined[1] for 6061-T6 aluminum and are: collision angle 5 - 20°, collision velocity 270 - 350 m/sec, with an impact pressure of at least 27 Kbar (391 Kpsi).

Another element of vital concern is the Collision Point Velocity. This term is sometimes called Flow Transition Velocity and is ideally above one half the bulk sonic velocity of the metal (2300 m/sec for aluminum), but never exceeding the total bulk sonic velocity. NOTE: This also helps determine the detonation velocity of the explosive to be used since they are interrelated.

To refresh our knowledge and gain some additional practice, several shots were fired to clad aluminum/stainless steel, 90 - 10 copper/stainless steel, 70 - 30 copper/stainless steel, and brass/stainless steel in plate form (Table I). Nominal size for all plates was 6" x 6" x .250". The stand-off, or interface, distances were varied from one-half the flyer plate thickness (1/2 T) to twice the plate thickness (2T). Since normal cylindrical cladding is accomplished with parallel surfaces, all plates were placed parallel. Using the chart (Figure 3) and past experience as guides, it was determined that explosive loading for the aluminum, brass, and 70 - 30 copper/nickel (CuNi) should be 12 - 15 gms/in^2 and for 90 - 10 copper/nickel it should be 10 - 12 gms/in^2 of surface area. Best results were obtained with explosive loads of 12 gms/in^2 for aluminum, 10 gms/in^2 for 90 - 10, 14 gms/in^2 for 70 - 30 copper/nickel, and 12 gms/in^2 for brass.

For the preceding tests, four different explosives were evaluated. These were:

DBA-10HV (Slurry)
Manufactured by IRECO, West Jordan, Utah

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[1] R. Wittman, University of Denver, Denver Research Institute, Denver, Colorado, The Influence of Collision Parameters on the Strength and Microstructure of an Explosion Welded Aluminum Alloy

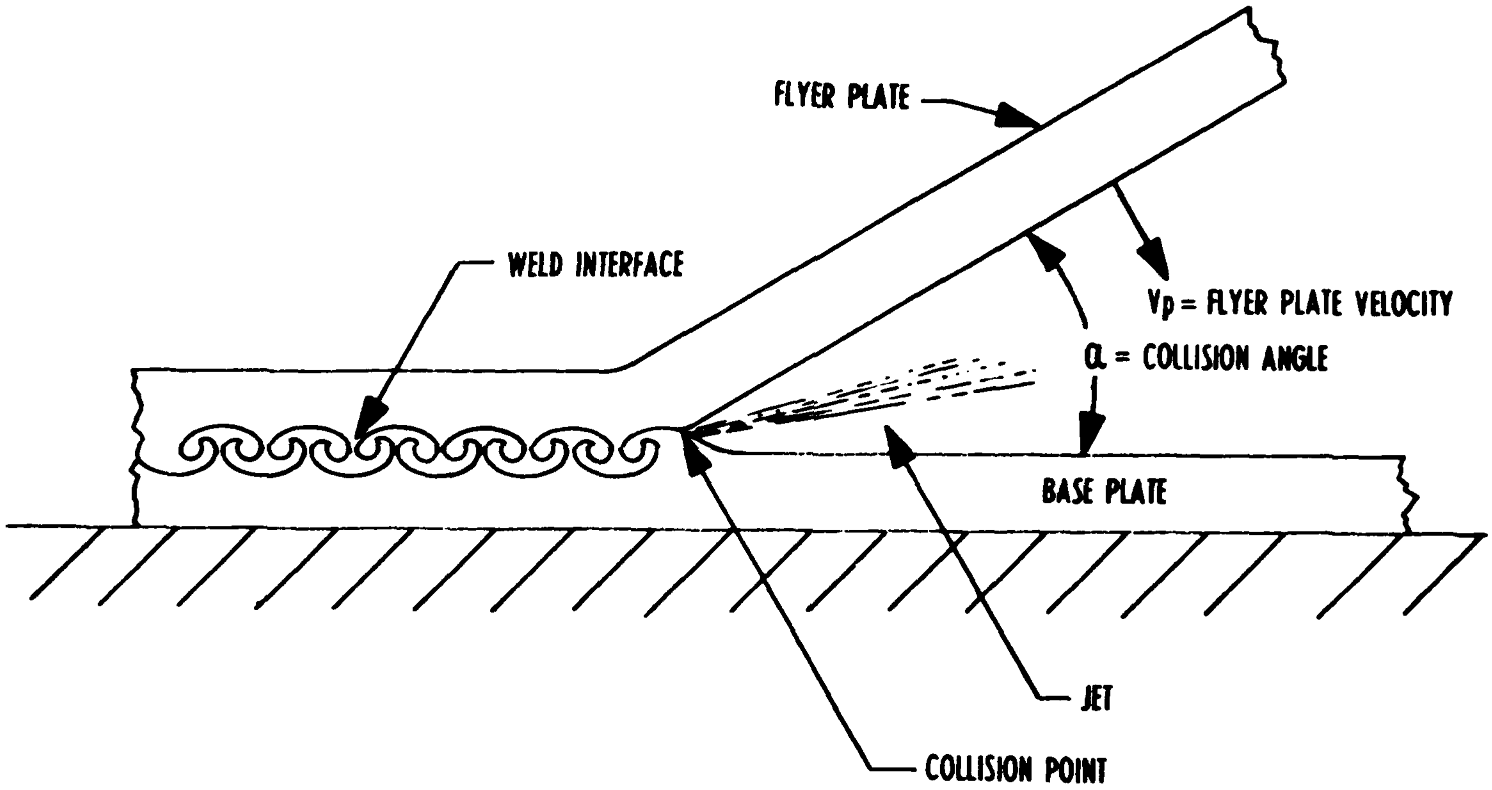


FIGURE 2 SCHEMATIC OF AN OBLIQUE COLLISION OF METAL PLATES LIKE THAT OBTAINED IN AN EXPLOSION WELDING OPERATION

TABLE I

Cladder Metal	Base Metal	Explosive	Explosive Loading (gms/in^2)	
6061-T6 Al	304 SS	TSE-1004	12	Good Weld
6061-T6 Al	304 SS	DBA-10HV	12	Good Weld
5086-H32 Al	304 SS	TSE-1004	11	No Weld
5086-H32 Al	304 SS	DBA-10HV	11	Weld 50% of Area
5086-H32 Al	304 SS	DBA-10HV	13	Good Weld
70-30 Cu/Ni	304 SS	SWP-5	13	Weak Weld 75% Area
70-30 Cu/Ni	304 SS	DBA-10HV	13	Weak Weld
70-30 Cu/Ni	304 SS	TSE-1004	13	No Weld
70-30 Cu/Ni	304 SS	TSE-1005	13	Weld-Plate Spalled
70-30 Cu/Ni	304 SS	DBA-10HV	14	Good Weld
70-30 Cu/Ni	304 SS	TSE-1004	14	Weak Weld
90-10 Cu/Ni	304 SS	DBA-10HV	10	Good Weld
90-10 Cu/Ni	304 SS	TSE-1004	11	Good Weld
90-10 Cu/Ni	304 SS	SWP-5	10	Good Weld
1/2 Hard Brass	304 SS	SWP-5	12	No Weld
1/2 Hard Brass	304 SS	TSE-1004	12	Good Weld 50% Area
1/2 Hard Brass	304 SS	DBA-10HV	12	Good Weld 85% Area
1/2 Hard Brass	304 SS	DBA-10HV	12	Good Weld
90-10 CuNi	304 SS	TSE-1005	10	Weld - Overloaded
5086-H32 Al	304 SS	SWP-5	12	Good Weld
5086-H32 Al	304 SS	DBA-10HV	12	Good Weld
70-30 Cu/Ni	304 SS	TSE-1005	11	Good Weld - Some Spall
70-30 Cu/Ni	304 SS	DBA-10HV	14	Good Weld 75% Area
5086-H32 Al	304 SS	SWP-5	12	Good Weld

FLAT PLATE WELDING SHOTS

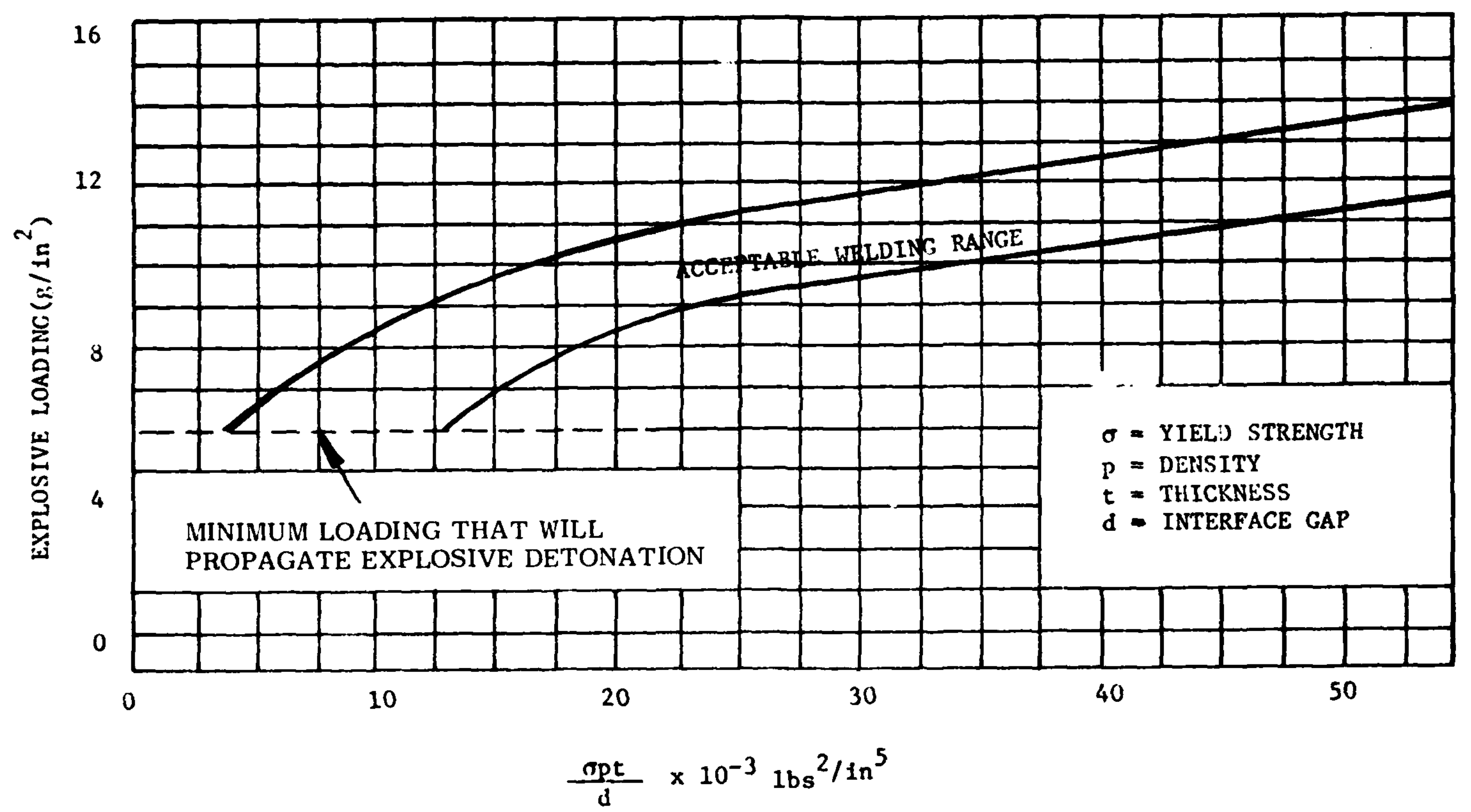


FIGURE 3 RELATIONSHIP OF THE IMPORTANT PROCESS VARIABLES FOR EXPLOSIVE BONDING WITH A LOW-DETONATION-VELOCITY EXPLOSIVE

SWP-5 (Granular)
Manufactured by Trojan-U. S. Powder, Spanish Fork, Utah

TSE-1004 and TSE-1005 (Flexible Sheets)
Manufactured by Thiokol Chemical Corporation, Brigham City, Utah

All were commercially available items but none were qualified for Navy use. All four were found to be suitable for explosive cladding of plates and were nominated for Navy qualification tests (two were later tested by Naval Weapons Center, China Lake (Appendix I)). Three are considered to be "slow detonating" explosives when compared to military standards with detonation velocities of 9,100, 11,100, and 13,000 feet per second (FPS) while the fourth detonates at 16,500. Detonation pressures also varied widely from 26 Kbar (377,000 psi) to 120 Kbar (1,740,000 psi). In order to better utilize time and materials, it was decided to use only one explosive (DBA-10HV) for the remainder of the project. This explosive was developed for commercial mining operations and is very adaptable to most configurations. The basic ingredients are ammonium nitrate and aluminum powder, which are shipped and stored separately until ready for use. When mixed in proper proportions, they form an explosive "slurry" having a density of 1.25 gm/cc, detonation velocity of 11,100 FPS, and a detonation pressure of 37.8 Kbar (555,000 psi). This mixture tends to thicken and is gelled within 2 - 3 hours; however, it does not get solid enough to cut up and handle without a container.

For the purpose of this report, all explosive charge weights were calculated as a relation to the area (in square inches) of the inside surface of the outer pipe. This is the surface that must be propelled, or compressed, onto the outside surface of the inner pipe with sufficient velocity and force to cause cladding to occur. Thus:

$\pi \times D \times L \times E$ = Total Explosive Weight
Where π = 3.1416
D = Inside Diameter of Al Pipe
L = Length of Al Pipe
E = Calculated Explosive Charge (gm/in^2)

To calculate the explosive weight needed to clad an aluminum pipe/tube with the dimensions of 2 inches inside diameter and 12 inches long with a desired charge of 12 gm/in^2 would be:

$$(3.1416) \times D\ (2) \times L\ (12) \times E\ (12) = 905 \text{ grams}$$

NOTE: This method of determining the explosive charge may vary at other installations, e.g., using the outside surface area of the inner pipe, etc. Again, the intent is only to provide one consistent basis applicable to any explosive cladding of a larger pipe to a smaller one.

The initial shot to clad two pipes together was on 8 inch long pieces of 6061-T6 aluminum with an inside diameter (ID) of 1.690 inches and 2.500 inches outside to standard 1 inch IPS schedule 20 "black pipe" (1.315" OD). Spacers were used 90° apart at top and bottom to insure equal stand-off, or interface, distances. The inside of the inner pipe was filled with wood's metal (Cero-Bend),

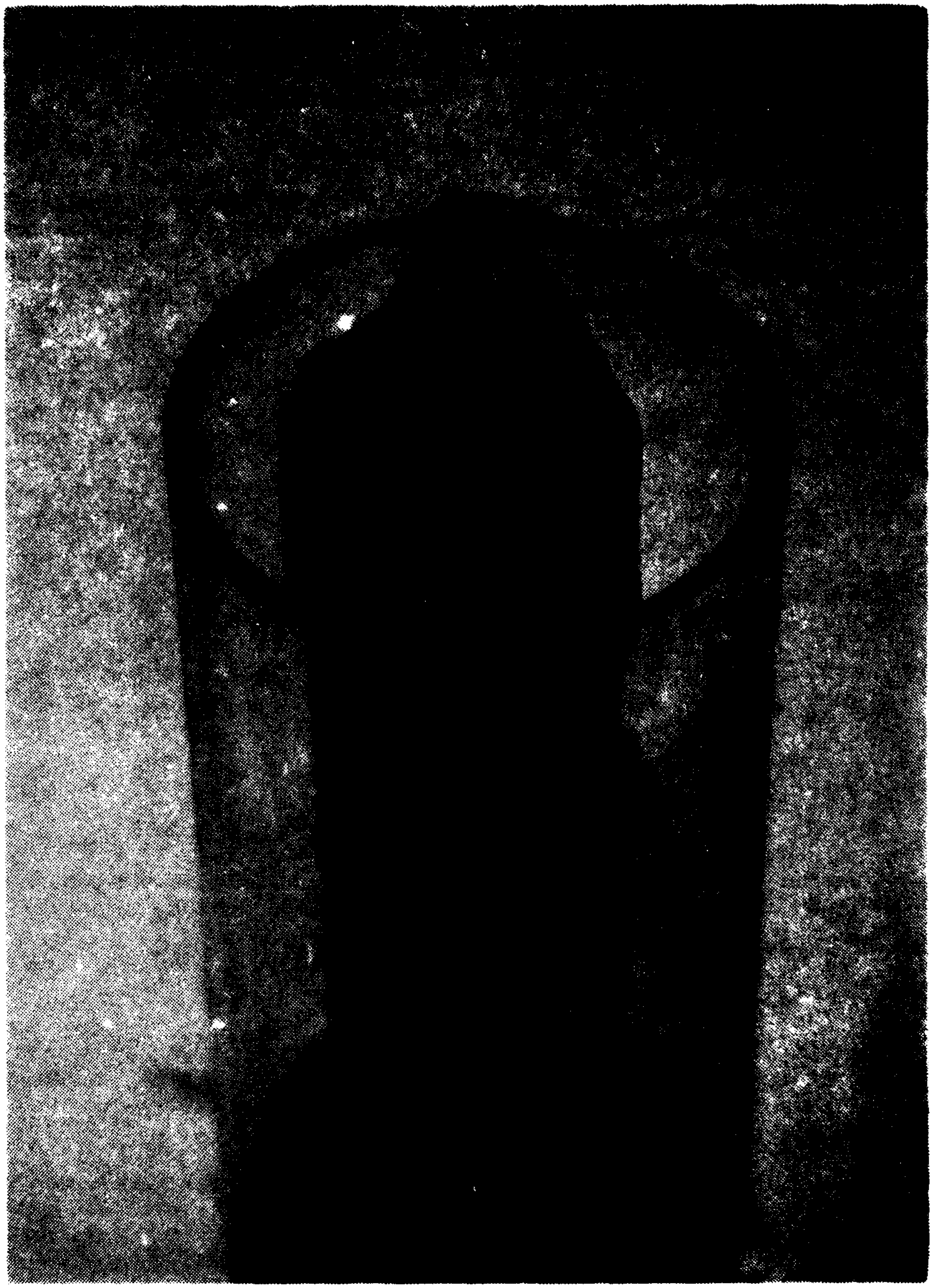


FIGURE 4 FIRING SETUP USING DETASHEET STRIPS

to keep it from being collapsed. The top of the entire setup was sealed to prevent introduction of foreign matter. The explosive (DBA-10HV) was contained between the aluminum and a cardboard tube with the amount being 850 grams (20 gms/in^2). The explosive was detonated simultaneously at four places by using narrow strips of Dupont Detasheet radiating from one centrally located electric blasting cap (Figure 4). After firing, the assembly was placed in hot water to remove the wood's metal, then sectionalized. Some areas showed signs of air or foreign matter entrapment, while only one side exhibited fair cladding. There was some evidence of degradation of the aluminum near the bondline. These indications pointed to at least three parameters to be altered: (1) more accurate location of the blasting cap to insure even initiation of the DBA-10HV; (2) a reduction in the explosive charge; and (3) evacuation of air from the interface area.

The second shot was fired using the same size steel and aluminum pipes. Two of the above parameters were changed, blasting cap location and explosive charge reduction. Two additional changes were made in the setup. A wood cone was placed between the sealing disc and the Detasheet/blasting cap (to reduce the bending radius over the sealing cap edge) and the assembly was placed on a wood box to isolate it somewhat from a dirt environment when fired. After detonation, the wood's metal was removed and the part inspected visually. The top had a "square" look showing the effect of the additional Detasheet's explosive force. The bottom end showed some spalling. At this point a decision was made to machine part of the aluminum off prior to sectionalizing. The deformed ends were cut off and the remainder put on a lathe for machining. When machined down to the bond area, the first inch showed only spots of cladding and the lower 2 1/2 inches were not clad. The remaining area appeared good and a one inch section was cut out for shear testing (piece failed at 5900 psi). Remainder of the material was sawed into sections to examine the bond integrity and microscopic structure.

Shot number three was an attempt to clad 6061-T6 to galvanized pipe. The steel pipe was 1 1/4" ID and 1.660" OD and the aluminum was 2" x 2.750" with the length being 8". The steel pipe was machined to 1.5" OD to remove the outer galvanizing and to give a .250" stand-off. The explosive used was DBA 10HV at a loading of 20 gms/in^2 (1005 gms). In order to conserve travel time and expense, this assembly was placed in a plastic bag and fired underwater at NAVORDSTALOU. NOTE. All air shots fired at NAVORDSTALOU must be less than one pound due to proximity of other activities. The results of this attempt were: no cladding and the presence of what appeared to be zinc oxide from the galvanized pipe.

A fourth shot was prepared and fired underwater. This trial used the earlier (shots 1 and 2) size 1 inch IPS steel pipe and 1.690" ID aluminum with a .405" wall thickness. The length was increased to 12 inches. Firing setup was the same as shot no. 3 except explosive loading was reduced to 16.3 gms/in^2 (1040 gms). After firing and the wood's metal removed from the inside cavity, this part had all indications of being clad, except for the top one inch and lower two inches. These ends were removed and one inch pieces were cut from top and bottom for destructive evaluation. The remaining seven inches was placed on a lathe and the aluminum was machined from approximately 1 1/4 inches of each end, then a one inch section machined from the middle (Figure 5). One small defect was found near the lower end which appeared to be a manufacturing flaw in the steel that had surfaced under the tremendous force applied. This part was saved and used as a demonstration piece.

Shots 5 through 11 and the results are shown in Table II.

Two changes were made for number 12 and succeeding shots. The length was increased to allow for non-clad areas at each end and have sufficient lengths for desired tests. The initiation method was changed to a disc with wedge shapes removed from the edges to permit bending over the end sealing cap and into the DBA-10HV (Figure 6).

Number 12 shot was fired to verify the possibility of cladding titanium to monel or inconel. This combination was suggested for use as filling and venting penetrations in cryogenic pressure vessels. Dimensions for this setup were: 2.067" ID x 2.375" OD x 12" long for the 400 monel and 2.625" ID x 3.5" OD x 12" long for the commercially pure titanium (CPTi). The only surface treatment was a light sanding to the OD of the monel and ID of the CPTi. Explosive used for this trial was a different commercial type, used because of its very low detonation rate (7100 FPS). This feature is very desirable when cladding titanium to minimize the forming and entrapment of titanium oxides. An additional feature of this shot was the use of a vacuum to assist in the removal of air from the stand-off space. The explosive loading was increased to 22 gm/in^2 to compensate for the lower detonation pressure of the explosive (22 Kbar) and higher yield strength of the titanium. This assembly was placed in a plastic bag and suspended approximately six feet underwater with the vacuum line extending to the pump located near the firing area. After retrieval from the water and removing the wood's metal, this part was placed on a lathe and a "clean-up" cut was made to remove surface irregularities. The part was then subjected to an ultrasonic test (UT) using an Automation Industries UM-771 reflectoscope and a 1/2 inch diameter transducer. All discrepancies were recorded and these questionable areas were exposed by sectionalizing to verify the findings. No defects were noted in the center 7 1/2 inches. The titanium was removed by machining except for a 2 inch wide collar at the center. Machining and destructive testing corroborated the UT.

Pieces 13 and 14 were 6061-T6 and carbon steel and were "air shots" fired at NWSC Crane, Indiana. Dimensions were: 1.750" ID x 2.250" OD x 14" long for the steel and 3.0" ID x 4.0" OD x 14" for the aluminum. Explosive loadings were 15.5 and 17 gm/in^2 respectively. Piece number 13 showed no indications of voids by UT, but the aluminum "peeled" when machined to the interface. Number 14 had UT indications of large defective areas. Upon sectioning, some unclad areas contained traces of what appeared to be carbon (or soot). Other spots looked shiny as if the aluminum were crystalized. The sooty material was determined to be carbon of no definite origin. However, this could be an explosion by-product introduced by lack of a complete seal at the initiation end. The shiny surfaces were not analyzed in the laboratory.

The above dimensions were used for shot number 15. This time the assembly was fired underwater in a plastic bag. Explosive loading was

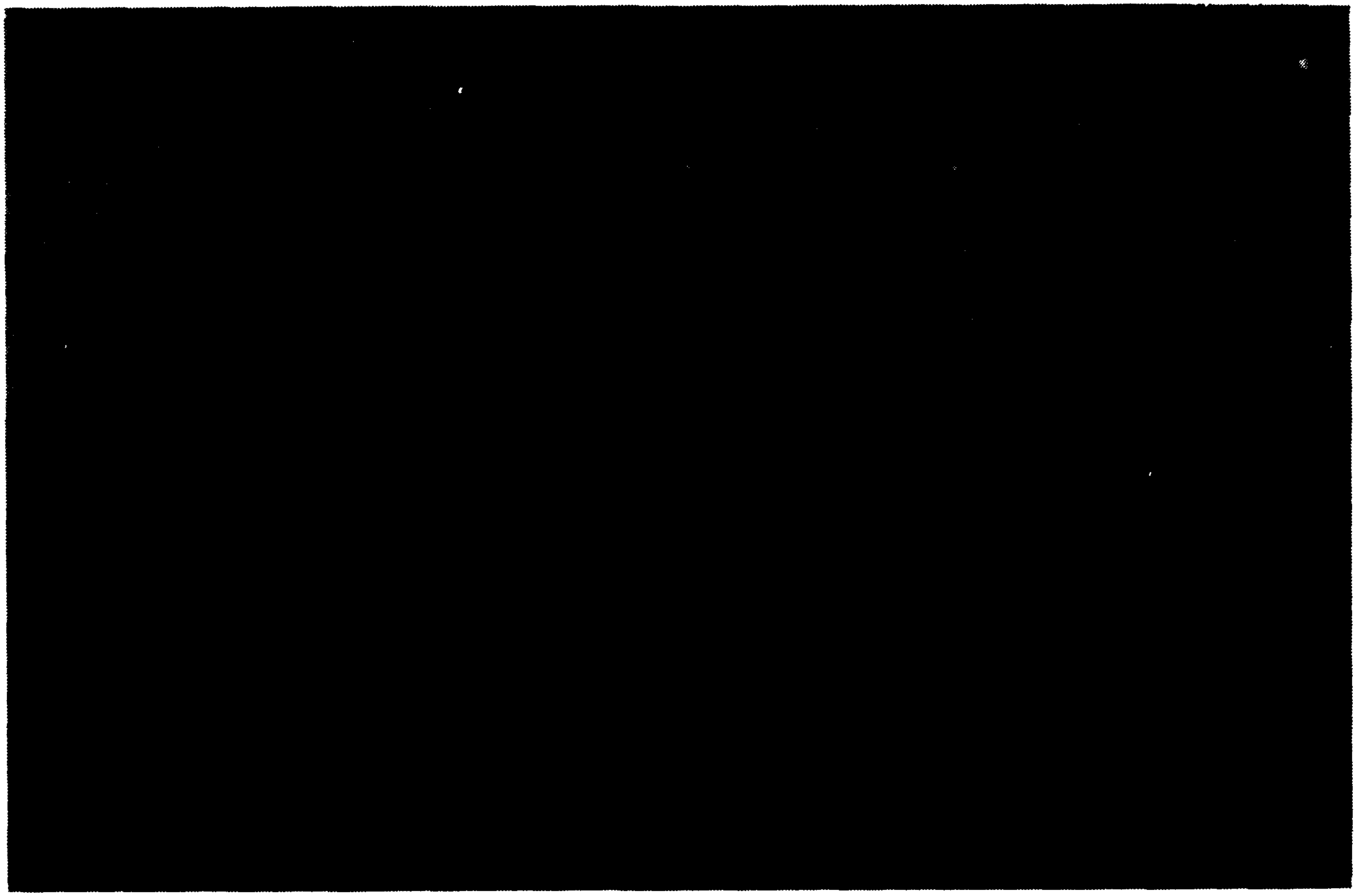


FIGURE 5 ONE INCH PIPE WITH TWO ALUMINUM COLLARS

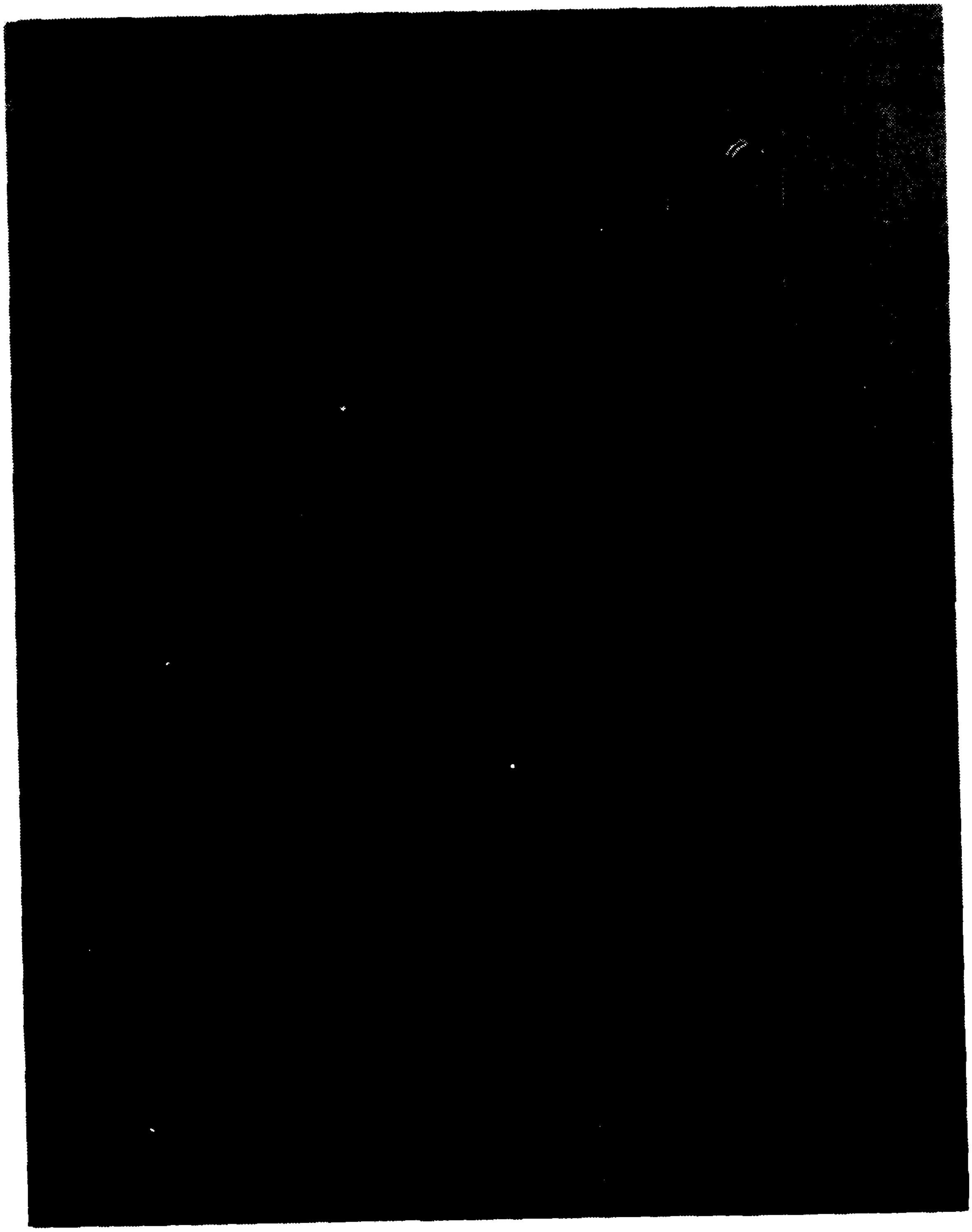


FIGURE 6 FIRING SETUP USING DETASHEET DISC

TABLE II

Shot Number	Inner Pipe	Outer Pipe	Explosive and Loading	Stand-off	Remarks
5	90/10 CuNi	6061-T6	DBA-10HV 16.7 gm/in^2	.500"	No cladding. Evidence of water in interface area.
6	90/10 CuNi	6061-T6	TSE-1004 16.2 gm/in^2	.250"	No clad.
7	6061-T6	90/10 CuNi	TSE-1004 16.2 gm/in^2	.250"	No clad. Results indicate too large explosive charge.
8	6061-T6	90/10 CuNi	DBA-10HV 12 gm/in^2	.250"	No clad. Some evidence of surface melt.
9	90/10 CuNi	6061-T6	DBA-10HV 12 gm/in^2	.250"	Weak clad. Pieces could be pried apart when sectionalized.
10	90/10 CuNi	6061-T6	DBA-10HV 11 gm/in^2	.250"	Good clad. Part machined and used for demonstration.
11	70/30 CuNi	6061-T6	DBA-10HV 15.4 gm/in^2	.125"	Good clad. Part machined and used for test and demonstration.

CYLINDRICAL TEST SHOTS

15.5 gm/in^2. No burned areas were found, but some shiny spots appeared near the lower end. Of the 14 inch part, only the central 8 inches had good cladding.

2.4 MID-PROJECT EVALUATION

Conferences held with Naval Ship Engineering Center (NAVSEC) and various Program Managers, Ships (PMS) representatives showed sufficient interest to warrant continuation of the project. Inspections of the parts on hand brought out several suggestions on improvement, primarily in the aluminum collar size and contour. The specimens were also presented to various shipbuilding facilities to obtain reactions to the explosive clad concept, materials most used, and the sizes.

Telephone consultations with other explosives cladding representatives regarding the shiny areas and the carbon entrapment resulted in four major changes in the firing setup: (1) aluminum alloy changed to 5086-H32, (2) stand-off reduced, (3) spall trap put into use, and (4) a vacuum system for the stand-off volume.

The 6061-T6 aluminum had been used because it was readily available and thought to be good for weldability, corrosion resistance, etc. The meetings with NAVSEC brought out that 5456 aluminum is normally used for all shipboard bulkheads and decks. This alloy is not readily available in pipe or tube configuration, however, 5086-H32 was acceptable and compatible with 5456-H116 or H117. Also, seamless tube should be used to obtain closer dimension control and, thereby, less preparation.

In the high energy area, a rule of thumb is that the stand-off for explosively cladding pipes should be as small as possible but not more than .100 inch. This dimension, as set for future effort on this project, varied from .035 inch for 3/4 inch to .065 inch for 2 1/2 inch International Pipe Size (IPS) for the inner pipe.

Use of the spall trap and vacuum were to reduce the "end effect", or non-clad distance, and reduce the chances of entrapping air to a minimum. By machining a spall trap for each size pipe, it was possible to create a custom fit stand-off for the bottom end, provide a location for the vacuum line, and a method of sealing the lower end of the aluminum. The top was sealed by using a silicon rubber (RTV) under the sealing disc.

2.5 IMPLEMENTATION

The initial trial using the preceding setup was fired "in air" at Naval Weapons Support Center (NWSC) Crane, Indiana. Materials used and descriptions were: 1 1/2 inch IPS (1.900" OD) 304 stainless steel 12 inches long for the inner pipe and 2" ID x 2 1/2" OD 5086-H32 aluminum as the cladder. The stainless was placed on a previously machined spall trap and filled with wood's metal. The aluminum was placed over a machined stand-off collar with a vacuum line provision. The explosive chamber consisted of a rolled and welded thin wall aluminum cylinder and the explosive loading was 10.2 gms/in^2 (770 gms). This setup was placed on a scrap wooden box to isolate it from the dirt, the vacuum line attached and the pump allowed to run for approximately 10 minutes prior to firing, blasting cap put in place, and detonated. There was some deformation of the

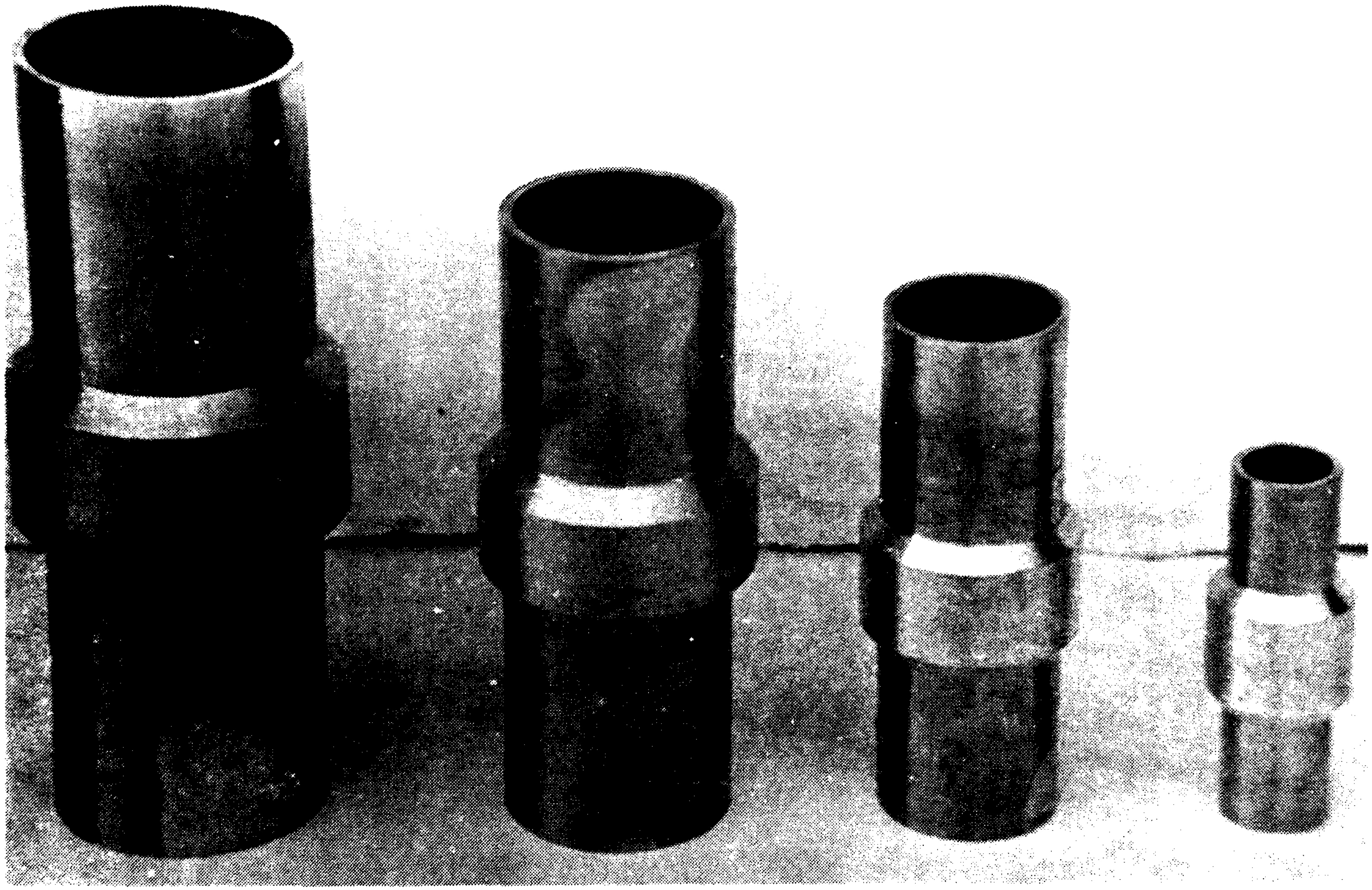


FIGURE 7 COMPARISON OF MACHINED 3/4, 1 1/2, 2, 2 1/2 INCH FITTINGS

lower end, but no spalling. Usable portion was obtained by removing 1/2 inch pieces of unclad material at the ends before UT inspection and machining. One inch at the top and 2 1/2 inches at the bottom were unacceptable.

Two additional shots (17 and 18) were fired at NWSC on 2 1/2 inch IPS stainless (2.875" OD) and 2.900 inch ID x 3.5 inch OD (5086-H32) aluminum. The OD of the stainless was machined to give stand-offs of .065 inch and .045 inch. The parts were 12 inches long; the explosives container made of thin wall aluminum; and the explosive loading was 10.1 gms/in^2. The first part (.065" stand-off) showed some defective areas when UT inspected, but was machined to verify the UT. The machined interface was also dye penetrant checked and showed some unclad areas. The remaining aluminum was removed except for a one inch wide collar which was subjected to shear test. The part failed at 9,100 psi (80,000 lbs total force). The second part (.045" stand-off) appeared to be clad over approximately 60% of the length. When cut into sections, the metals could easily be separated with a hammer and chisel. One one inch section was shear tested and failed at 5000 psi (44,150 lbs total force).

Parts 19 and 20 were also fired at NWSC Crane. Both parts were of 2 1/2 inch IPS stainless and 2.900" ID x 3.5" OD 5086-H32 aluminum, one of 12 inches and one 24 inches length. The OD of the stainless was machined to provide a stand-off of .055 inch (2.790" OD). Setup included use of a spall trap, vacuum system, disc type Detasheet initiator, aluminum explosives container, and wood box. The explosive loading was 10.1 gms/in^2 in each case. These attempts were unsuccessful. Three pieces 9 inches long were machined and in each case the aluminum "peeled off" when the cutting tool exposed the interface area. Each part had an area along one side that was eroded and contained carbon residue. The only explanation was a lack of complete detonation on the one side resulting in a distorted collision point at the interface.

Two additional pieces (21 and 22) were fired using the above setup, but with stand-offs of .060" and explosive loadings of 12 gms/in^2 (1300 and 2600 gms). Three pieces, one from the 12 inch and two from the 24 inch part, were UT inspected, machined, and dye penetrant checked. All three appeared to have acceptable cladding. One inch pieces from each were shear tested (failed at approximately 5900 psi). These finished parts were retained for further testing and demonstration. Since no carbon residue was in evidence, and the cladding appeared uniform, the distorted collision point theory (shots 19 and 20) was tentatively accepted.

With the receipt of 5086-H32 alloy aluminum tubes having dimensions that required no machining to give the proper stand-off, setup time was greatly reduced. With the increased speed and better control of most parameters, no detailed descriptions were maintained for each shot; only those of special significance. Approximatley 125 additional shots were fired to clad 5086 auminum to 304 stainless steel in 3/4, 1 1/2, 2, and 2 1/2 inch IPS sizes. These parts were subjected to non-destructive tests; some destructively tested, and others machined into penetration fittings for exhibition and further testing. A comparison of these sizes is shown in Figure 7.

One penetration fitting had short sections of pipe welded to each end (Figure 8). While this photograph does not show the part in place, it does indicate one method of attaching the mating pipes as welded by an average welder. No special preparation is required, but the mating pipes must be cut to the exact lengths to insure a proper welding fit.

Two parts from earlier trials were welded into a section of one-half inch thick plate to show how penetration fitting would look in place (Figures 9A and 9B). The materials of these parts were 304 stainless steel (9A) and 400 series monel (9B) pipe with collars of 6061-T6 aluminum. These were conventionally welded into 5456 aluminum plate that had been previously prepared by cutting 3 1/2" holes and machining 30^{o} angles on both sides of the holes, leaving a one-eighth inch flat edge. Photomicrographs of this 6061 Al/304 SS interface (Figures 10A and 10B) show a wavy interface rather than the "sawtooth" effect seen in flat plate clads. This variation has no apparent effect on the strength of the cladding. Also worthy of note is the apparent "melt" or mixture of the parent metals trapped in the interface.

The final configuration for firing short pieces is shown in the schematic drawing (Figure 11). The setup steps are as follows:

1. Place stainless steel, or other, pipe on a base with a vacuum line attachment. Base should be machined with steps to aid in locating each added piece of setup.

2. Seal to prevent molten wood's metal from leaking.

3. Fill inside of pipe with wood's metal or combination of steel rod and wood's metal. Remove tape seal (if used) when cool.

4. Place aluminum pipe/tube to be clad around stainless pipe, adjust stand-off equally on all sides, and seal top and bottom. NOTE: Top seal used at NAVORDSTALOU is a metal disc with the stand-off machined as a step to reduce possibility of foreign matter admission.

5. Check vacuum seal.

6. Put explosives container in place, seal bottom, and adjust top to insure equal room for explosives on all sides.

7. Secure lifting lines and adjust. These may be any disposable material that will support the weight. NOTE: These steps (7, 9, 10, 11, and 12) are necessary only if the shot is to be fired in water.

8. Move entire setup to the edge of water tank, or other firing area.

9. Fill explosives container with the pre-mixed slurry explosive.

10. Install the initiation cone and blasting cap. Tape in place to avoid any possible shifting, using strips of duct tape.

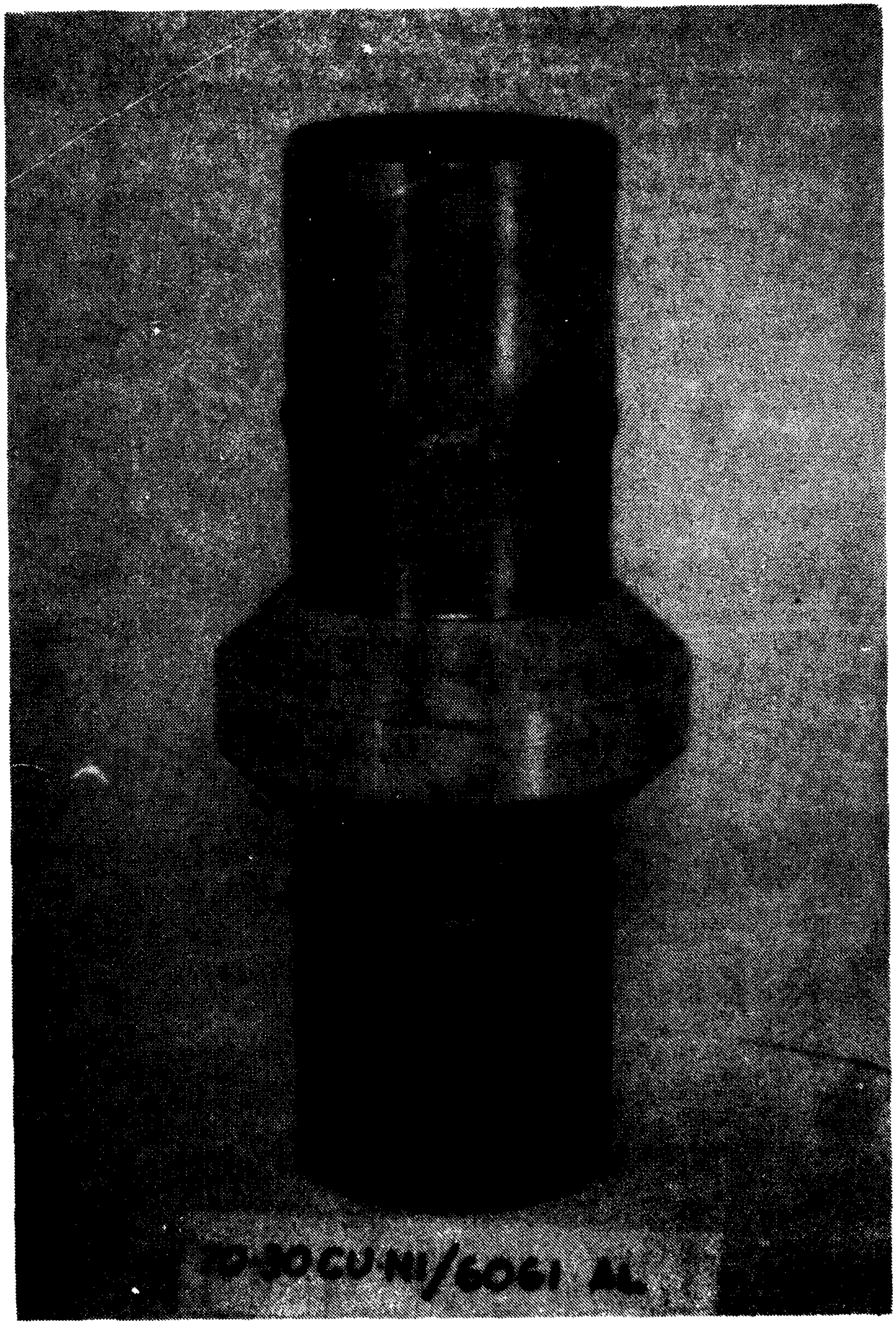
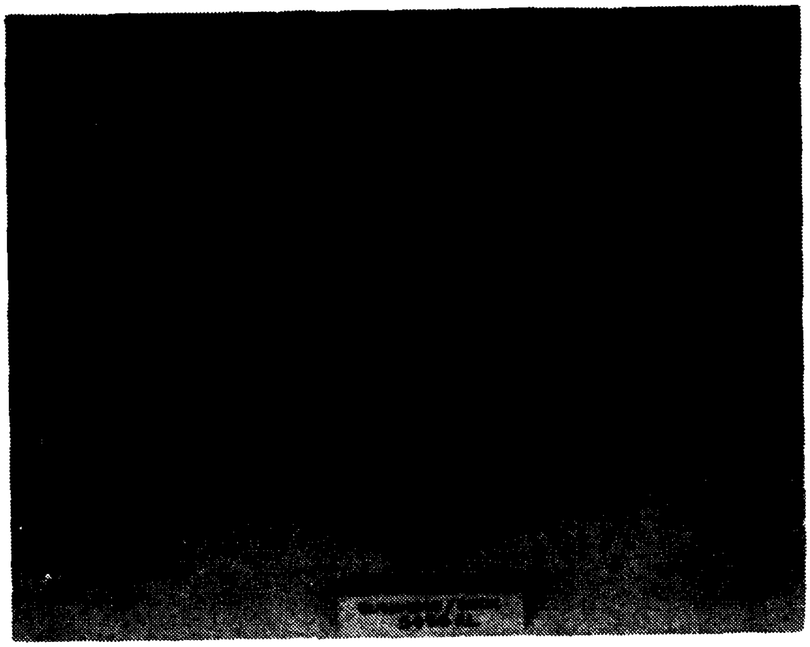
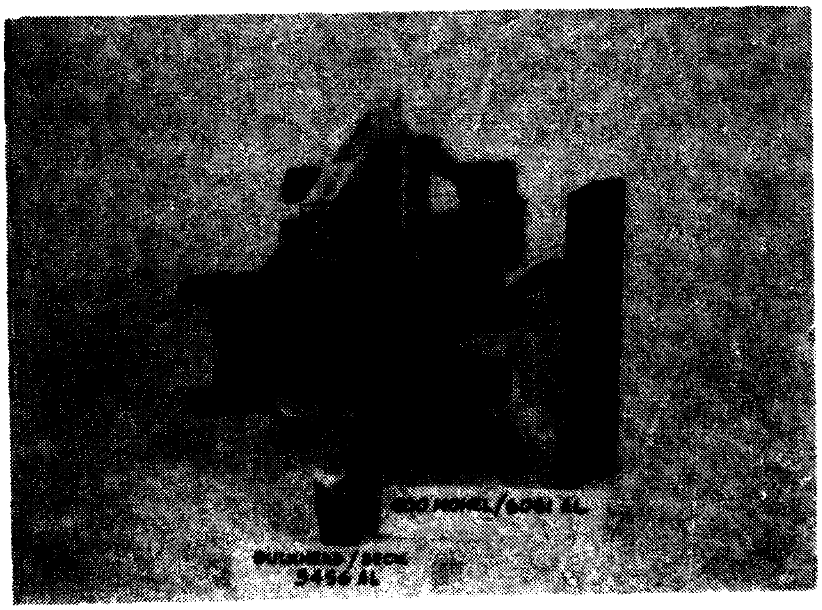


FIGURE 8 TYPICAL PENETRATION FITTING/PIPE WELD

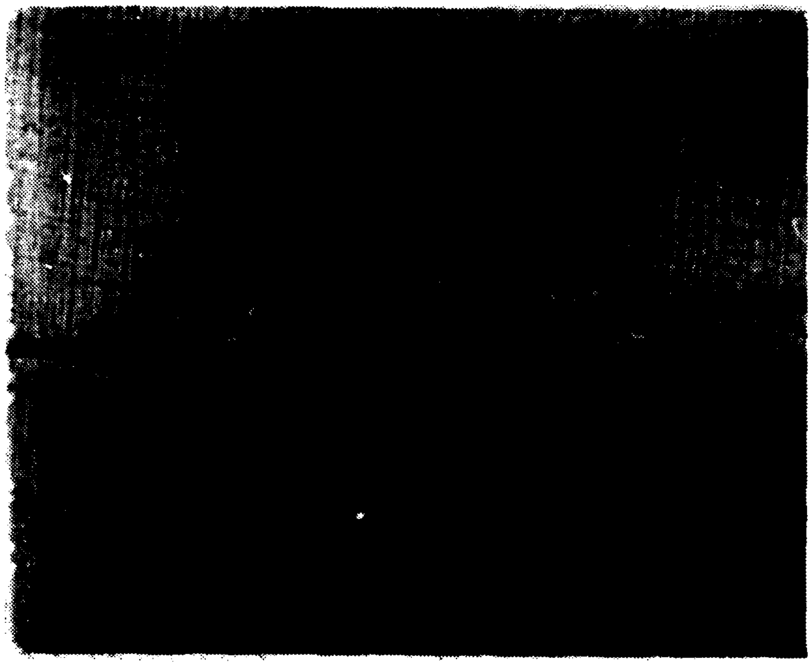


A - ALUMINUM/STAINLESS STEEL



B - ALUMINUM/400 MONEL

FIGURE 9 TYPICAL PENETRATION FITTINGS AS WELDED IN PLACE



A - 50X MAGNIFICATION

B - 400X MAGNIFICATION

FIGURE 10 PHOTOMICROGRAPHS OF AL/SS EXPLOSIVELY CLAD INTERFACE

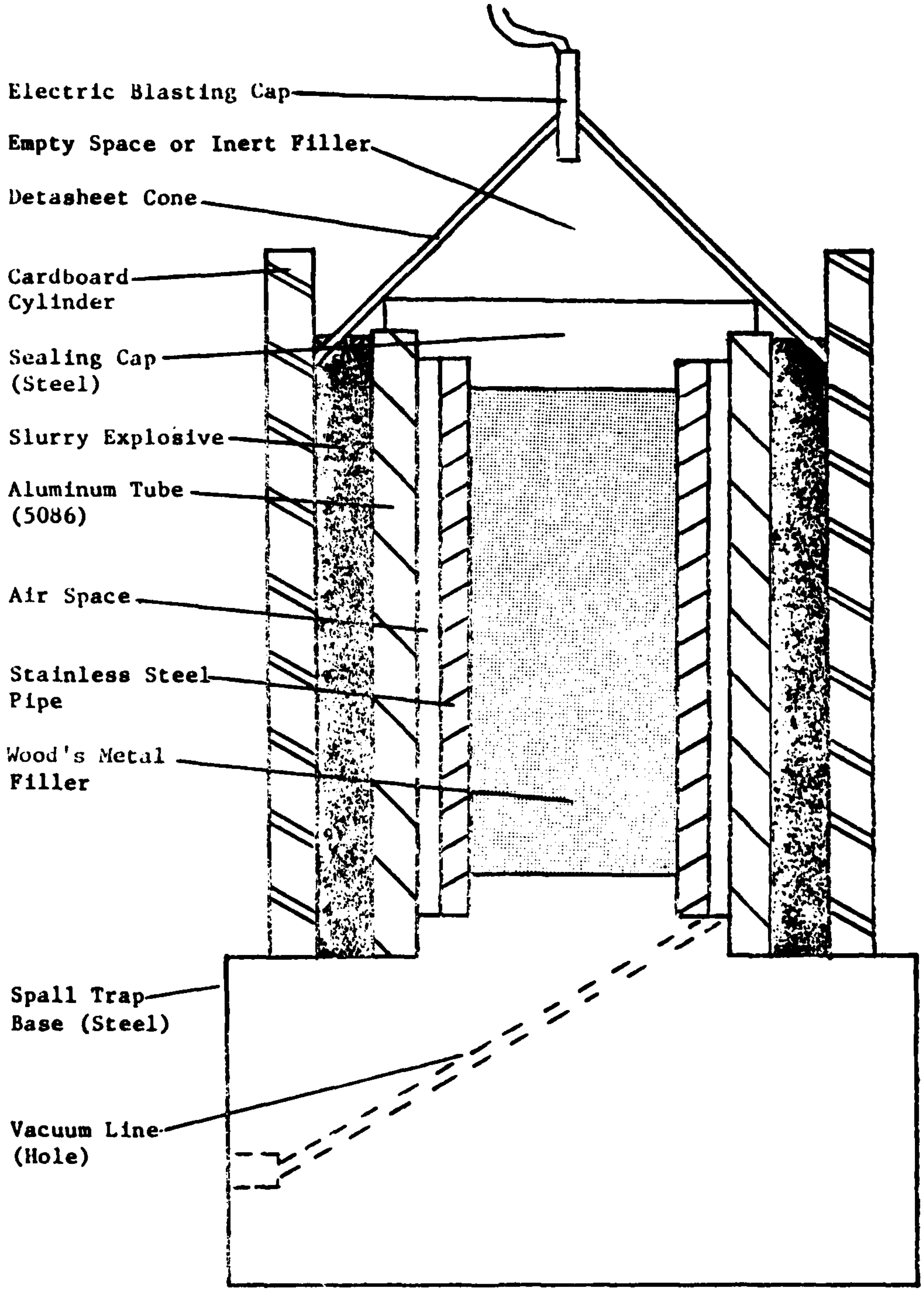


FIGURE 11 SCHEMATIC FIRING CONFIGURATION

11. Lift with hoist (or other means) and slip plastic bag up around the entire assembly far enough for end to be clear of the water.

12. Lower into water at least four feet.

13. Fire.

Remove the wood's metal by submerging in hot water. The part is now ready for NDT and machining. It should be noted that this firing sequence does not occur within a span of an hour or two. Time must be allowed for sealants to harden or cure and for the wood's metal to cool.

2.6 TESTING

Sections from shot nos. 11 and 15 were "salt spray" tested. Alloys for these were 6061-T6/70-30 CuNi and 6061-T6/carbon steel. The results, Appendix II, were very encouraging. Approximately one half of each section was covered with a single coat of spray enamel. During the first 100 hours, the painted surfaces showed almost no corrosive attack while the unpainted areas were moderately attacked. The CuNi had no indication of corrosion. After 200 hours the single coat of enamel remained intact on all areas except the steel. While each metal was attacked individually, there appeared to be no penetration at the weld interface and no apparent galvanic action. The most encouraging result of this test is that no penetration occurred in the bond, or interface area, although the aluminum corrosion appeared most intense near the bondline. Figures 12 (A) and (B) show the effects of the single coat of paint on both sections two years after the salt spray test and removal of the paint. Both pictures show where the metals were corrosively attacked. The area covered by paint is still clearly visible.

Figure 13 shows the bond strength of aluminum/carbon steel. This is a typical shear test specimen of the penetration fitting. Since the configuration of the explosively clad pipe does not lend itself to the normal tensile test coupons, the shear test is a primary method of testing the integrity of the bond. The standard shear test specimen used in this project is approximately 1 1/4 inches long with the aluminum machined off each end leaving exactly one inch clad portion. This specimen is placed in a Tinius-Olsen tensile tester with the bottom on a short collar somewhat larger than the steel and a plate pushing down on the bare steel inner pipe. The shear force is measured in total pounds needed to fail the specimen and the stress pounds per square inch (psi). This is determined as follows. The test specimen is designed to put one inch of clad area in shear so the shear stress can be read directly from the shear force $\sigma_s = F/\ DL$. This specimen is not quite the usual failure mode. The bond between the aluminum/carbon steel was such that the aluminum actually failed some distance away from the steel. Shear failure for most pieces tested occurred above the strength of the aluminum.

A contract was awarded to Cincinnati Testing Laboratories, Inc. (CTL) to fatigue test the penetration fittings welded into plates (Appendix III). Original specifications called for comparison of the explosively clad fittings with flanged and adhesive bonded fittings. A late adhesives problem caused the adhesive

A - ALUMINUM/CARBON STEEL

B - ALUMINUM/70-30 CuNi

FIGURE 12 SALT SPRAY SPECIMENS
TWO YEARS AFTER TEST

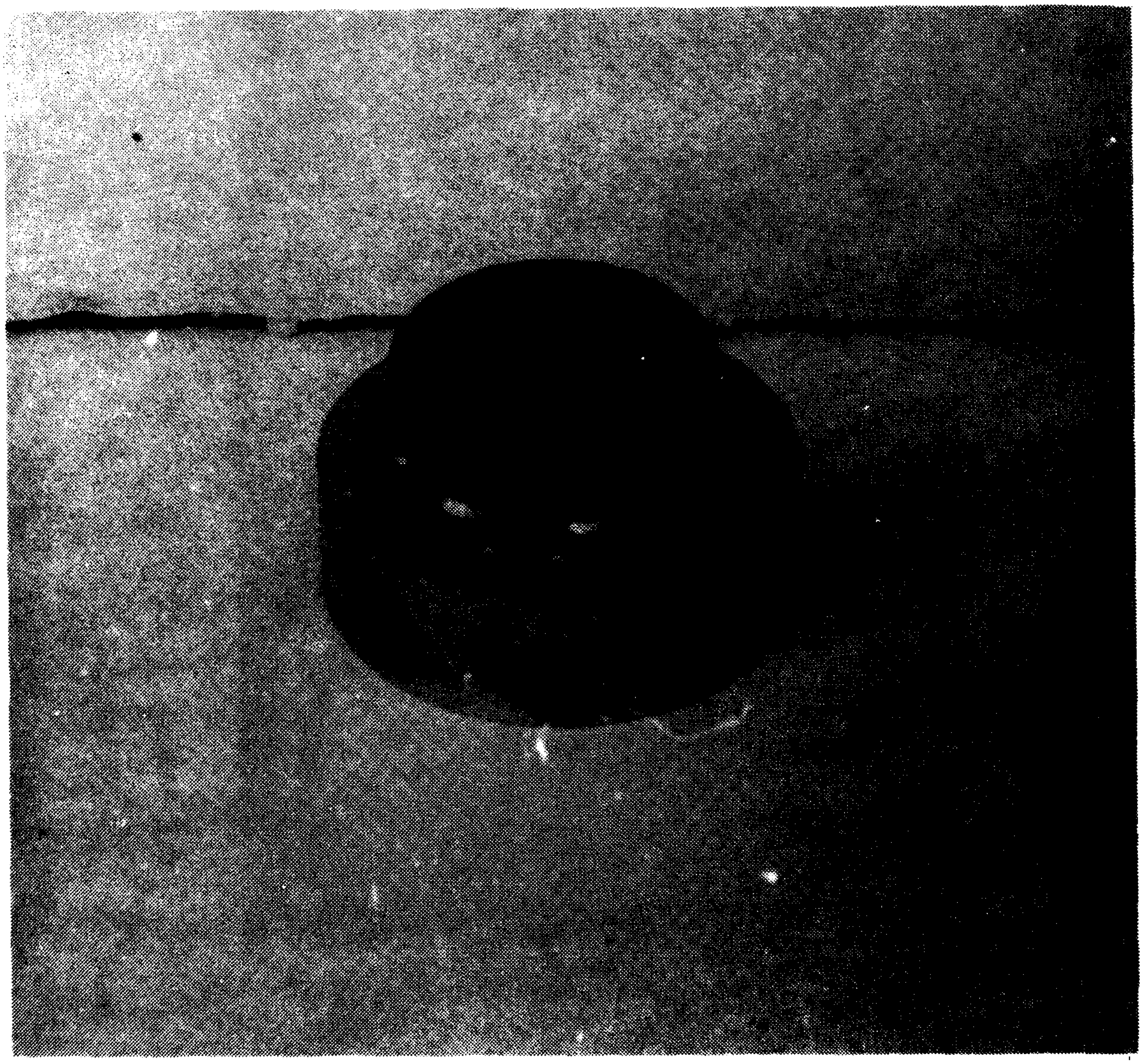


FIGURE 13 SHEAR TEST SPECIMEN

bonded part to be discarded so there was only one other method compared. The final test program tended to evaluate the plate material with parts welded into in more than the actual explosively clad material. As can be seen in the CTL report (Appendix III), no failures occurred in any explosively clad area, while the flanged fitting failed at the bolt holes. All test specimens were made in accordance with Rohr Industries specification, as the Rohr designed SES is the one selected for development.

SECTION 3

CONCLUSIONS

The following conclusions were reached from this project:

1. Aluminum pipe/tube can be explosively clad to the outside surface of a variety of dissimilar pipes in sizes from 3/4" to 6" IPS and lengths up to 26".

2. The stand-off should be less than .075" in most instances but be great enough to allow the escape of air and surface contaminants. The aid of a vacuum system should be used when possible.

3. The central void of the inner pipe must be filled with a low melting temperature substance (as wood's metal) to avoid collapse of the pipe. The low melting temperature facilitates filling and removal. NOTE: A steel rod can be used to reduce the amount of wood's metal used as long as the rod is surrounded by the wood's metal.

4. It is possible to locate unclad areas, or irregularities, using ultrasonic scanning methods. Use of an underwater automatic rotating system reduces the possibility of missing small defects when compared to hand scanning. By using a "wet" recorder, in conjunction with a reflectoscope, it is possible to have a permanent map of the piece as well as an instant audible and visual indication of flaws. The audible portion is obtained by triggering an alarm set on the reflectoscope.

5. The present method of producing explosively clad penetration fittings of dissimilar metals is a viable process for a limited number of parts. Due to the amount of time involved, it is not an ideal method for a large production effort.

SECTION 4

RECOMMENDATIONS

The following are recommended to further refine the explosively clad penetration fitting process:

1. Develop a method for cladding longer lengths of pipe/tube. While some work has already been done in this area, there is still too much column bending to allow for accurately removing the excess aluminum. The ability to fill the longer lengths with wood's metal is still questionable also.

2. A more reliable method of automated ultrasonic testing is needed. The laboratory type equipment used for this project is suitable for parts up to 6 inches diameter and 12 inches long and a capacity of 12 inches by 48 inches is recommended as a minimum.

3. A standard method is needed for setting the sensitivity of the ultrasonic transducer. Some equipment can be set to pick up the smallest variations while others will record only larger discrepancies. A maximum acceptable unclad area should also be defined as in MIL-J-24445A (SH) for explosively clad plates.

4. Minimum shear strengths and a method for obtaining these need to be resolved. The method in use at NAVORDSTALOU, and described earlier in this report, is recommended since it needs minimum measurements and calculations.

5. A fatigue study is recommended for the explosively clad area. The study covered in this report did not exert the vibratory stresses on the pipes that would be experienced during a ship's operations. While the study performed by CTL was deemed sufficient by Rohr designers, and was vibratory in nature, the stresses were applied more to the conventional welded area. A fatigue study should be designed and conducted where the loading will be applied to the explosively clad area and not to the bulkhead.

APPENDIX I

NWC Technical Memorandum 3743
(Abridged)

QUALIFICATION TESTS OF COMMERCIAL EXPLOSIVES DBA-10HV AND TSE-1005

by

D. L. Harp
Conventional Weapons Division
Ordnance Systems Department

March 1979

Naval Weapons Center
China Lake, California 93555

INTRODUCTION

BACKGROUND

The Naval Ordnance Station (NOS), Louisville, Ky., requested the Naval Sea Systems Command (NAVSEA) to approve the use of the commercial explosives DBA-10HV, TSE-1004, TSE-1005, and SWP-5 for special applications (explosive cladding and forming).* NAVSEA provided the following initial requirements for the interim qualification of these explosives.**

INTERIM QUALIFICATION REQUIREMENTS

DBA-10HV, TSE-1004, TSE-1005, and SWP-5 were identified as "metal-working" explosives. The data listed below were selected as providing appropriate characterization of metal-working explosives. In general, all data were to be obtained in conformance with the test specifications given in NAVORD OD 44811, Vol. 1 (Safety and Performance Tests for Qualifications of Explosives) so that they could be compared with those of standard explosives. Alternatively, data for at least one standard Navy explosive (NAVORD OP-3613, Revision 1, "List of Explosives for U.S. Naval Weapons"), of comparable sensitivity, obtained under identical conditions, could be supplied together with the information on the explosive to be interim qualified. The specified requirements were:

Hazard Classification: DOT classification with supporting test documentation. No hazard classification was required for DBA-10HV, since this material is shipped and stored in the form of separate, nonexplosive components.

Detonation Velocity: Data supplemented by a description of the test conditions, providing information such as the loading density and charge diameter.

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* NOS Louisville, Ky., Ltr 85:TRM: lsw, 8020, 5 March 1976.

** NAVSEA Ltr 0332A/HA, Ser 258 of 15 Aug 1977.

Self-Heating and Thermal Stability: Standard DTA or DSC curves and slow cook-off tests designed to establish the time to decomposition as a function of temperature and charge size.

Sensitivity Tests (Electrostatic, Large-Scale Gap, Friction, Impact): The requirements of NAVORD 44811, Vol. 1 for interim qualification of main charge explosives.

Composition: The composition of all explosives in terms of specification limits, e.g., PETN ± 1%.

For the slurry explosive DBA-10HV, DTA or DSC and electrostatic, friction, and impact sensitivity data for the dry composition was also required.

PROPOSED TEST PROGRAMS

The Naval Weapons Center was funded by the Naval Ordnance Station, Louisville, Ky.[1/] to study available data regarding the specified metal working explosives and to conduct tests as necessary to obtain additional data. The data available at that time are summarized in Table 1. On the basis of that summary, and since the most urgent need at NOS Louisville was for approval to use DBA-10HV and TSE-1005, it was recommended that the explosives under immediate consideration be limited to those two. As required by NAVSEA INST. 8020.5 (paragraph 5.c.(6)), a letter containing proposed test programs was sent to NAVSEA before tests were begun[2/]. The proposed test programs are summarized in Figures 1 and 2.

[1/] NOS Louisville, Ky., Work Request No. N00197-78-WR-80017 of 1 March 1978 to Naval Weapons Center.

[2/] NWC official letter 3262/DLH:em Ser 4819 of 13 July 1972 to NAVSEA (SEA-0332).

TABLE 1. Pertinent Characteristics of Metal-Working Explosives.

CHARACTERISTIC \ EXPLOSIVE	DBA-10HV	TSE-1004	TSE-1005	SWP-5
HAZARD CLASSIFICATION	NOT APPLICABLE REFERENCE 1	HIGH EXPLOSIVE, CLASS A, TYPE 8 PER BUREAU OF EXPLOSIVES TWX 1-012387C284 DATE 10/11/73 REFERENCE 2	HIGH EXPLOSIVE, CLASS A, TYPE 8 PER BUREAU OF EXPLOSIVES TWX 1-012387C284 DATE 10/11/73 REFERENCE 2	HIGH EXPLOSIVE CLASS A DOT TARIFF 19 REFERENCE 3
DETONATION VELOCITY	3380 $^m/_s$ REFERENCE 4	4000 $^m/_s$, 12mm DIA. UNCONFINED. DENSITY = 1.20 $^g/_{cc}$ REFERENCE 5, p. 12	5750 $^m/_s$, 12mm DIA UNCONFINED. DENSITY = 1.79 $^g/_{cc}$ REFERENCE 5, p. 12	(1830 $^m/_s$) DENSITY = 1.04 REFERENCE 3
THERMAL DATA	NOT AVAILABLE	DTA REPORTED, REFERENCE 5, p. 22 NO COOKOFF DATA AVAILABLE	DTA REPORTED REFERENCE 5, p. 20 NO COOKOFF DATA AVAILABLE	NOT AVAILABLE
SENSITIVITY	NOT AVAILABLE	(TSE-1004 / COMP C-4) IMPACT (cm, 2.3KG WGT) (117) (107) FRICTION (KG) >(29) >(29) ELECTROSTATIC (J) > 8 > 8 NOL GAP TEST (CARDS) 300 220 REFERENCE 5, p. 14	(TSE-1005 / COMP C-4) IMPACT (cm, 2.3KG WGT) (117) (107) FRICTION (KG) >(29) >(29) ELECTROSTATIC (J) > 8 > 8 NOL GAP TEST (CARDS) 280 220 REFERENCE 5, p. 14	IMPACT SENSITIVITY 2kg - 100cm. + 10kg - 100cm. + REFERENCE 3
COMPOSITION	REFERENCE 6	REFERENCE 7	REFERENCE 7	REFERENCE 8

( ) INDICATES CONVERSION FROM UNITS REPORTED IN REFERENCE

REFERENCES:

1. LTR 0332A/HA, SER. 258, DATE 15 AUG. 1977, FROM NAVSEASYSCOM TO NOS LOUISVILLE (CODE 852).
2. LTR DATE 24 JAN. 1978, FROM THIOKOL / WASATCH DIVISION, P.O. BOX 524, BRIGHAM CITY, UTAH 84302 TO NWC CHINA LAKE (CODE 3262).
3. TECHNICAL BULLETIN NO. 007 DATE DEC. 1968, TROJAN – U.S. POWDER, EXPLOSIVES TECHNICAL DIVISION 17 NORTH SEVENTH STREET, ALLENTOWN, PA. 18105.
4. LTR GLH: mp DATE 16 DEC. 1968 FROM INTERMOUNTAIN RESEARCH AND ENGINEERING CO., INC., 3000 WEST 8600 SOUTH, WEST JORDAN, UTAH 84084 TO NOS LOUISVILLE.
5. MUNSON, W.O., "SPECIALTY EXPLOSIVES DEVELOPMENT," THIOKOL / WASATCH DIVISION, P.O. BOX 524, BRIGHAM CITY, UTAH 84302 (PUBLICATION NO. 0373-731468).
6. TECHNICAL INFORMATION TRANSMITTAL, CONTROL NO. 7-4349-2, INTERMOUNTAIN RESEARCH AND ENGINEERING CO., INC., 3000 WEST 8600 SOUTH, WEST JORDAN, UTAH 84084.
7. LTR RJS-53-78 DATE 5 AUG. 1978 FROM THIOKOL / WASATCH DIVISION, P.O. BOX 524,BRIGHAM CITY, UTAH 84302 TO NOS LOUISVILLE.
8. LTR WJC: kd DATE 7 JAN. 1977 FROM IMC CHEMICAL GROUP, INC., P.O. BOX 360, SPANISH FORK, UTAH 84660 TO NOS LOUISVILLE.

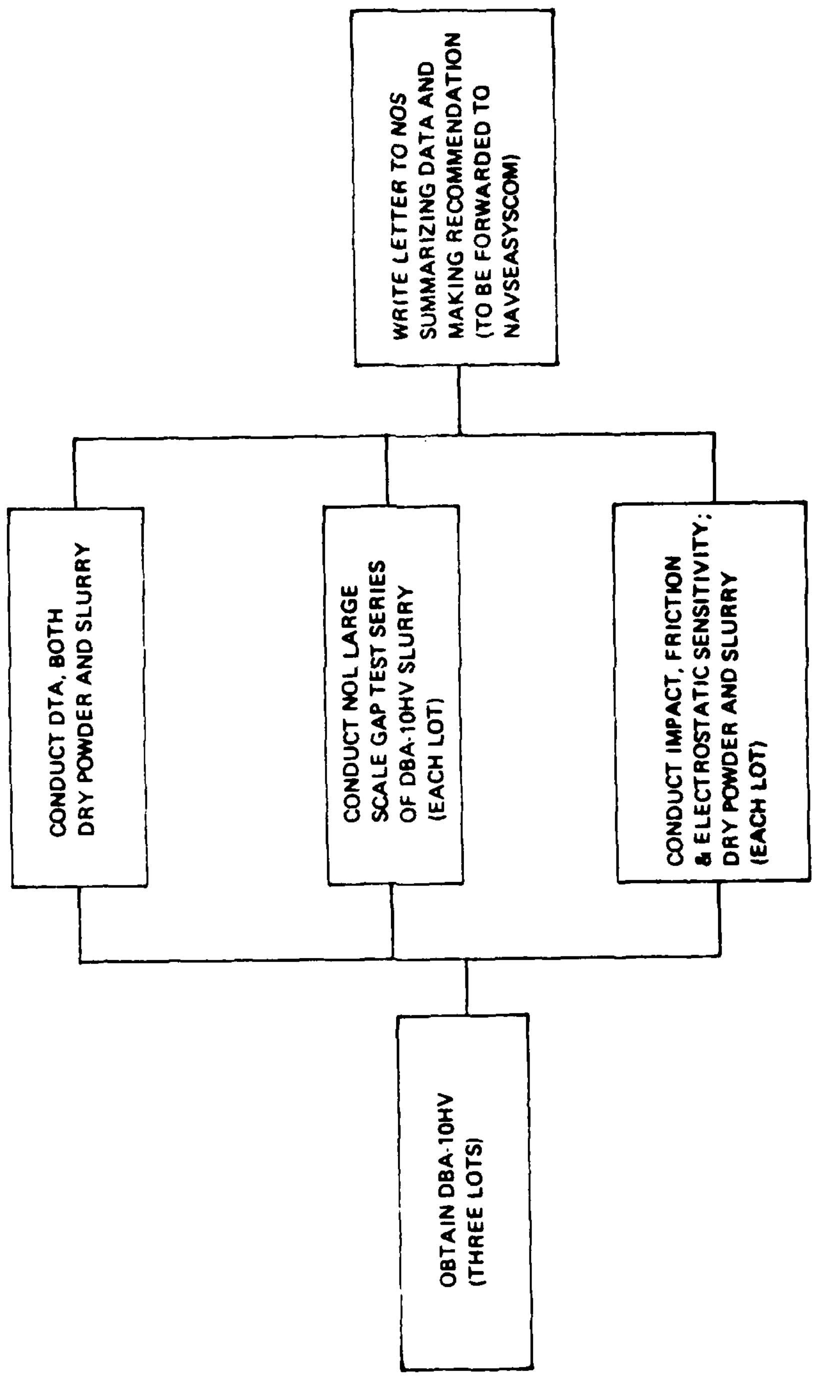

FIGURE 1. Proposed Test Plan for DBA-10V.

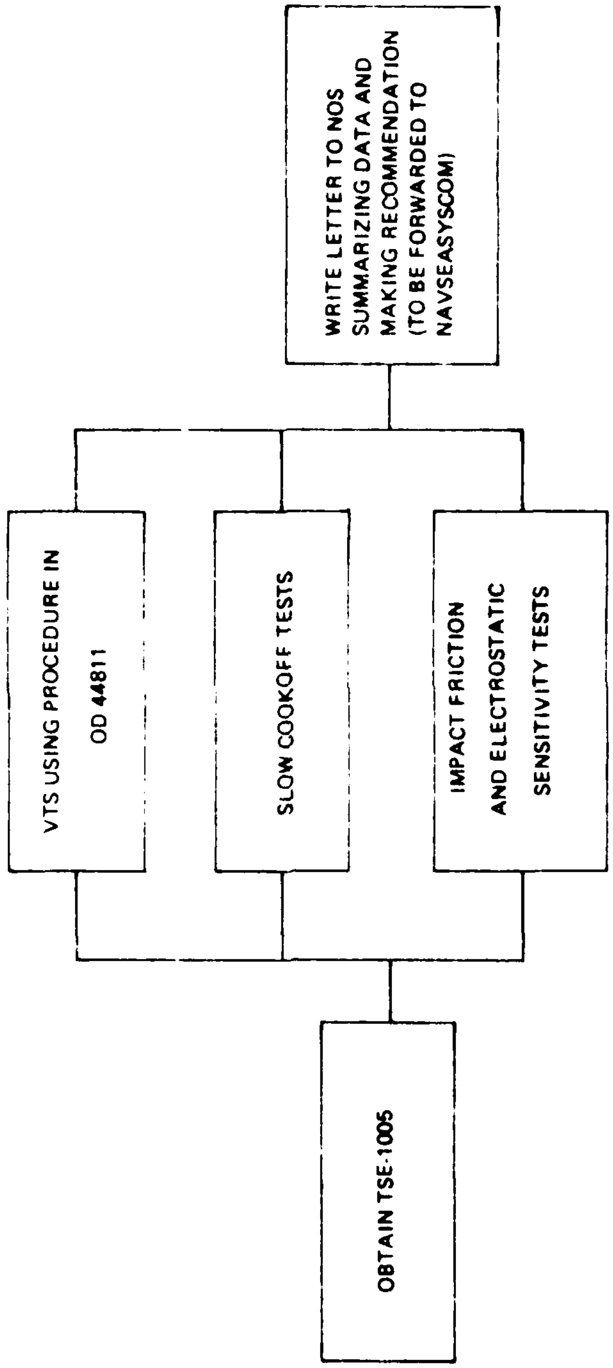

FIGURE 2. Proposed Test Plan for TSE-1005.

OPNAV 5216/144 (REV 6-70)
S/N-0107-770-6099
DEPARTMENT OF THE NAVY

Memorandum

DATE:

FROM: Daniel L. Harp

TO: Head, Code 3262

SUBJ: Large-scale gap tests of IRECO DBA-10HV explosive slurry

Enclosure: Original data and test results for large-scale gap tests of IRECO DBA-10HV explosive slurry

1. A series of standard Naval Ordnance Laboratory Large-Scale Gap Tests (NOL LSGTs) was conducted using DBA-10HV slurry made from each of three lots. Enclosure (1) includes a sketch showing the arrangement of components for the gap tests. The topmost "card" for each firing was a 3 mil (8×10^{-3} cm) thick disk of Mylar (Trademark for polyethylene terephalate manufactured by E. I. DuPont de Nemours & Co., Inc., Wilmington, Del.) attached to the bottom of the steel tube with epoxy cement. Thus it was possible to fill the steel tube with wet slurry, using the following procedure:

a. 150 g of liquid oxidizer was measured into a plastic container.

b. Fuel powder was added until the net weight in the plastic container was 200 g.

c. The two components were then mixed until the powder appeared to be reasonably well dispersed throughout the liquid.

d. The mixture was allowed to set at ambient conditions for 1 hour, during which time it thickened.

e. The steel LSGT tube was filled with thickened slurry, avoiding visible bubbles or void spaces.

f. The LSGT was conducted.

Enclosure (1) contains a graphical presentation of the gap tests that were conducted, with the fuel lot for each firing identified. Since no difference in shock sensitivity for slurries made from the different lots was apparent, the data for all of the firings after No. 11 were grouped together for a standard Bruceton analysis. That analysis indicated a gap value for 50% probability of detonation of 3.85 inches, with an estimated variance of 0.01872 inches.

Daniel L. Harp

TESTS OF EXPLOSIVES

DBA-10HV EXPLOSIVE

Description

DBA-10HV is a slurry explosive manufactured by Intermountain Research and Engineering Co., Inc. (IRECO), 3000 West 8600 South, West Jordan, Utah, 84084. It is shipped and stored as two separate components, an aqueous solution of oxidizer (ammonium nitrate and sodium nitrate) and a dry fuel powder consisting primarily of aluminum and sulfur. These components are mixed and detonated at the point of use.

Impact, Friction, and Electrostatic Sensitivity

Impact, friction, and electrostatic sensitivity were measured on the dry fuel, the slurry, and the dehydrated slurry. The results, compared to recent measurements with RDX and TNT, are shown in Table 2. These results indicate that while the material is wet it is reasonably safe to handle. Even though the dry fuel is sensitive to electrostatic ignition, and the slurry becomes more sensitive when it dries, the measurements indicate that both can be handled safely by using normal precautions.

Large-Scale Gap Tests

Appendix A presents the results and original data for large-scale gap tests (LSGT) that were conducted with DBA-10HV slurry made from each of three lots. The material for each test was allowed to dry for 1 hour between the time it was mixed and the time the test was conducted. This procedure was followed in order to obtain a reasonable simulation of field use conditions. However, it also resulted in a relatively low density for the material being tested, presumably because of evaporation of the water. The average percent of theoretical maximum density (TMD) for the 40 samples tested was 66.6% with a variance of 1.82%. Since the variance in the measurements is so small, it is unlikely that the low densities were the result of carelessness in filling the sample tubes.

TABLE 2. Sensitivity Measurements of DBA-10HV Compared to Two Commonly Used Explosives.

MATERIAL		HANDLING SENSITIVITY		
		IMPACT cm	ABL FRICTION lb	ELECTROSTATIC J
DBA-10HV FUEL POWDER	LOT B-1	10/10 NF[a]	10/10 NF[b]	0.20
	LOT B-2	10/10 NF[a]	10/10[b]	0.19
	LOT B-3	10/10 NF[a]	10/10 NF[b]	8/10 NF[c]
DBA-10HV WET SLURRY	LOT B-1	10/10 NF[a]	10/10 NF[b]	10/10 NF[c]
	LOT B-2	10/10 NF[a]	10/10 NF[b]	10/10 NF[c]
	LOT B-3	10/10 NF[a]	10/10 NF[b]	10/10 NF[c]
DBA-10HV SLURRY AFTER DRYING	LOT B-1	141	5/10 NF[b]	10/10 NF[c]
	LOT B-2	68	832	10/10 NF[c]
	LOT B-3	78	1000	10/10 NF[c]
RDX		11-15	331-589	10/10 NF[c]
TNT		41	309	10/10 NF[c]

[a]At test apparatus maximum of 200 cm.
[b]At test apparatus maximum of 1000 lb.
[c]At test apparatus maximum of 0.25 J.

Differential Thermal Analysis

Differential thermal analyses (DTAs) of both explosives were obtained by monitoring the temperature difference between a sample of the material under study and a reference sample, as the two samples were heated together at the rate of 5°C per minute. The reference sample for each analysis contained indium. The melting of the indium at 156.61°C provided an accurate temperature reference. The temperature difference between the samples was monitored with a bare-bead type K thermocouple. The test sample consisted of 30 milligrams of material in a 5-millimeter glass heating tube.

Differential thermal analyses were obtained for each of three lots of DBA-10HV fuel powder. Slurries were made by combining fuel from each of the three lots with oxidizer in the ratio by weight of one part fuel to three parts oxidizer. Each of the three slurry lots was analyzed beginning both 1 hour after mixing and after drying. The thermograms obtained for each of the three fuel lots are shown in Figure 3. Figure 4 is the thermogram of the dried oxidizer, and Figure 5 shows thermograms of slurries made from each of the three fuel lots. The thermograms of the dried slurry were essentially the same as those shown in Figure 5, except that the endotherm between 100 and 150°C was much less pronounced. Each analysis shown in Figure 5 was begun 1 hour after the slurry was mixed. Table 3 is a summary of the temperatures at which the first exotherm began for each of the conditions analyzed for DBA-10HV.

TSE-1005 EXPLOSIVE

Description

TSE-1005 is a flexible sheet explosive manufactured by Thiokol, Wasatch Division, P.O. Box 524, Brigham City, Utah, 84302. It consists primarily of PETN and a binder plus additives to modify the detonation velocity.

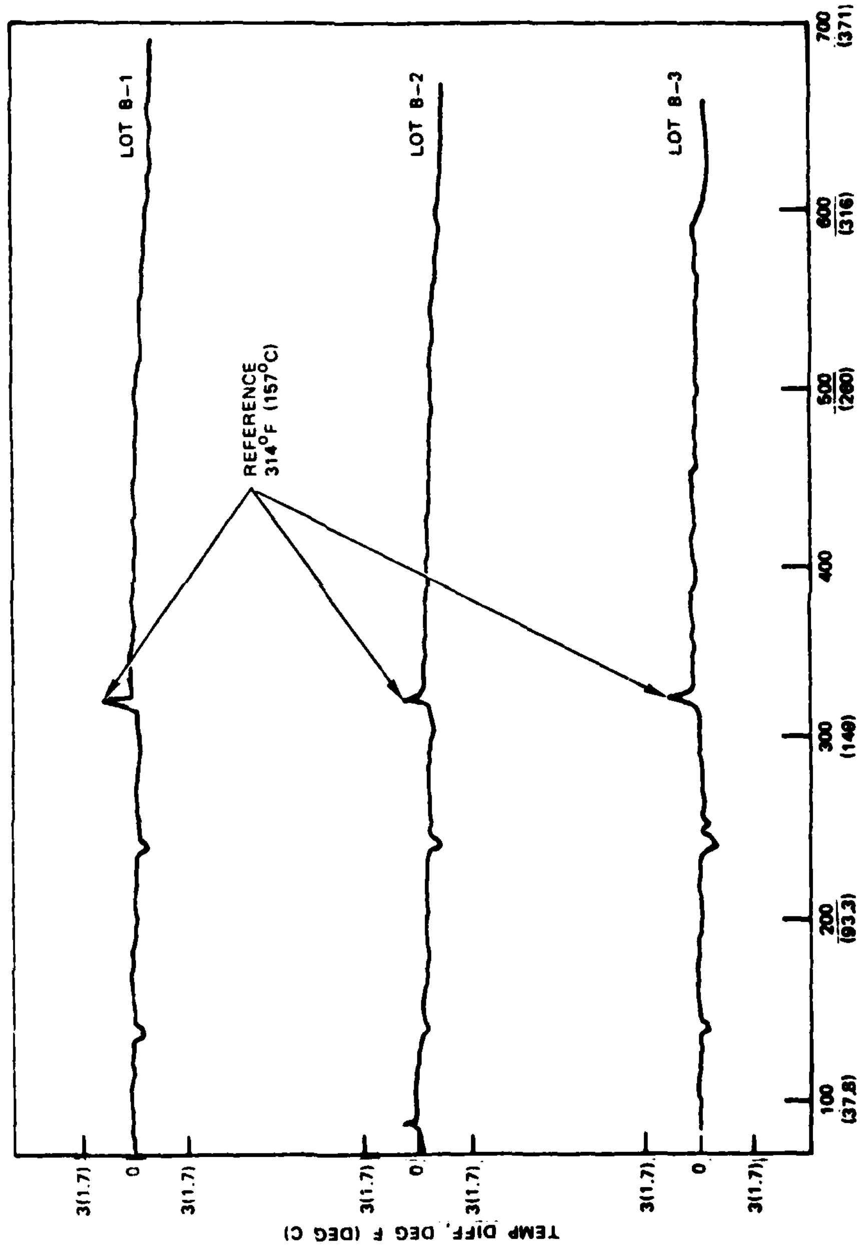

FIGURE 3. DTA Thermograms for Three Lots of DBA-10HV Fuel.

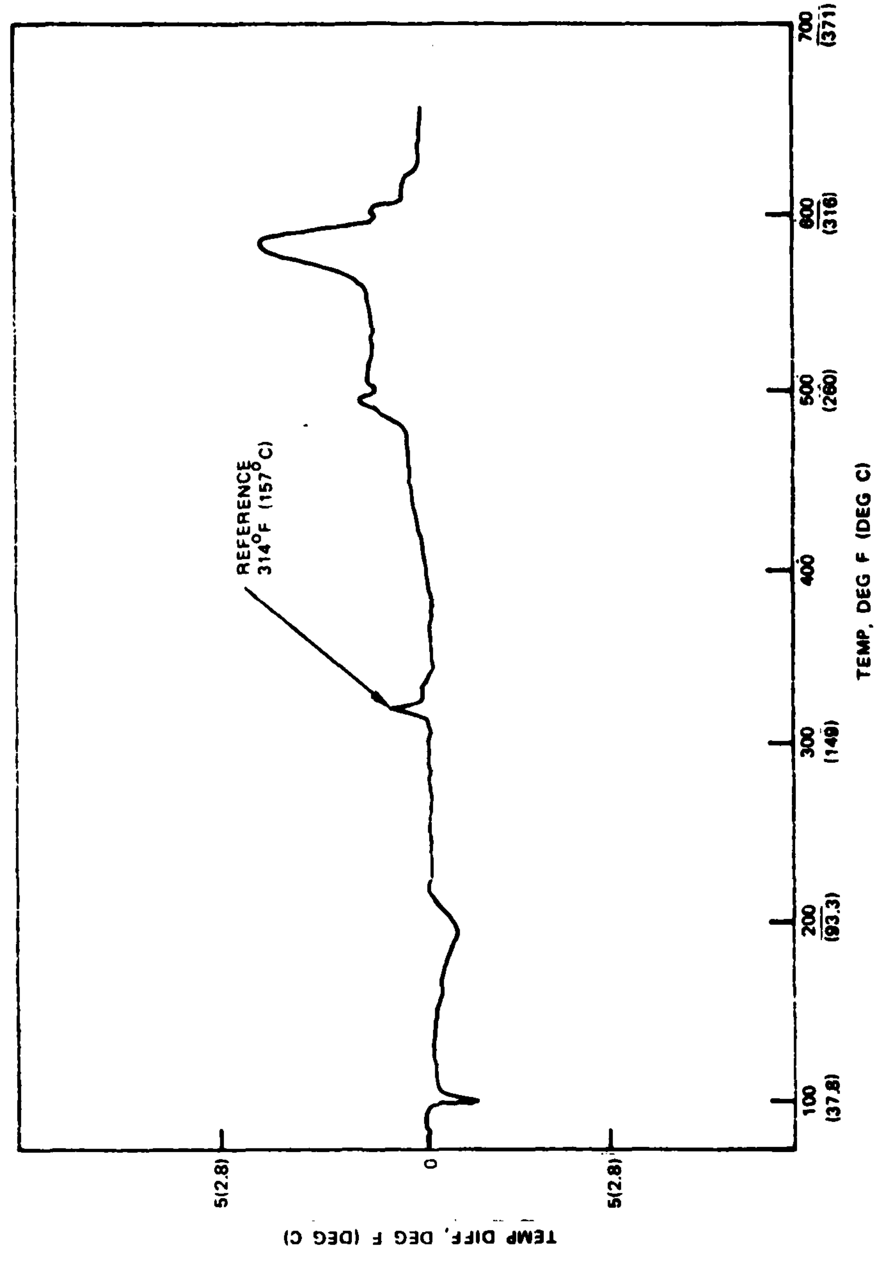

FIGURE 4. DTA Thermogram of Dried DBA-10HV Oxidizer.

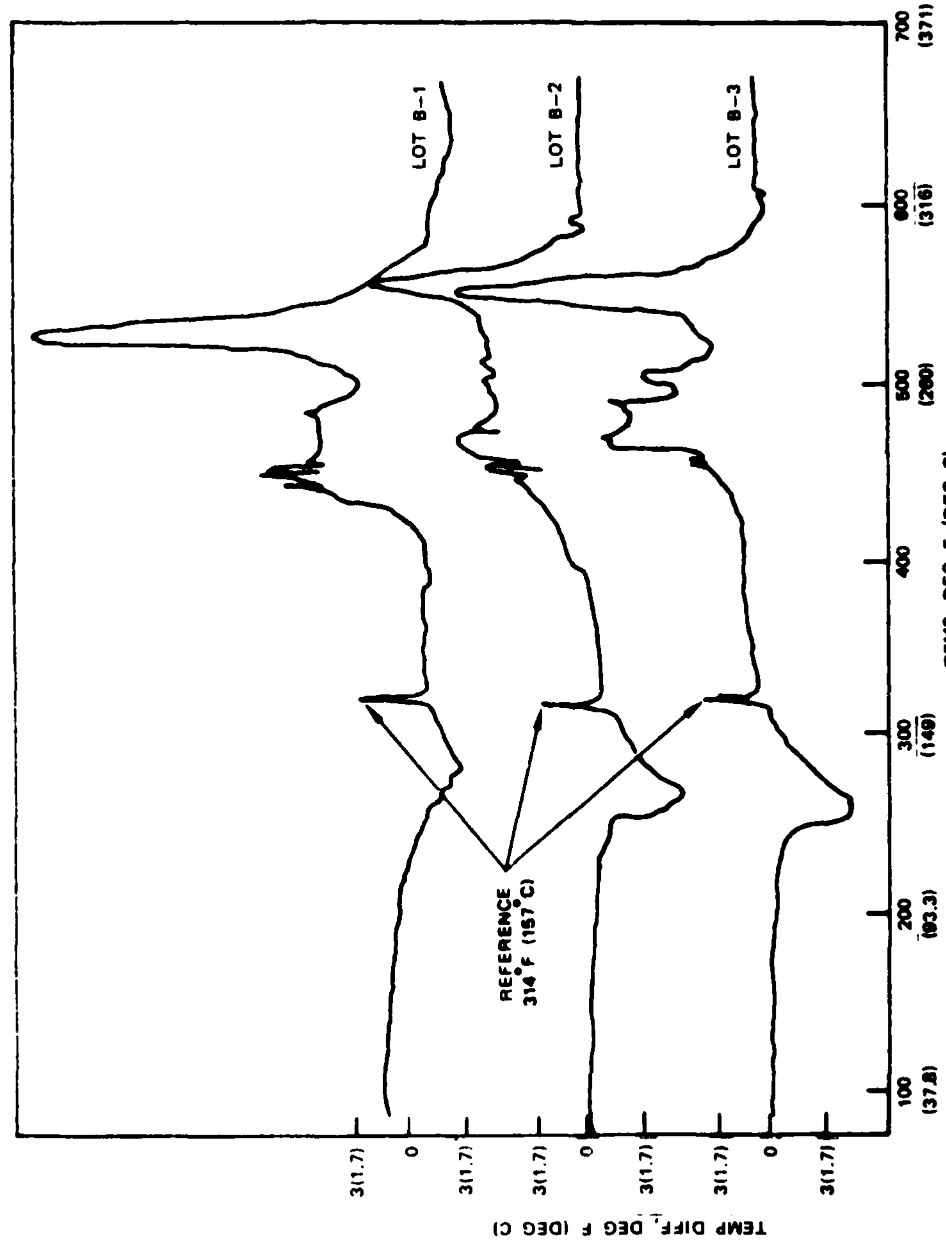

FIGURE 5. DTA Thermogram of Slurries Made From Each of Three Lots of DRA-10HV Fuel.

TABLE 3. Summary of DBA-10HV DTA Data.

Specimen	Onset to first exotherm, °F (°C)
Fuel:	
Lot B-1	None
Lot B-2	None
Lot B-3	None
Dried oxidizer	380 (193)
Slurry:	
Lot B-1	410 (210)
Lot B-2	340 (171)
Lot B-3	340 (171)
Dried slurry (18 hours at 165°F):	
Lot B-1	345 (174)
Lot B-2	405 (207)
Lot B-3	355 (179)

Characterization

Considerable characterization of TSE-1005 has been done by the manufacturer[3/]. Table 4 shows the results of additional vacuum thermal stability (VTS) and impact sensitivity tests, Allegheny Ballistic Laboratory (ABL) friction sensitivity tests, and electrostatic sensitivity tests conducted at NWC and compares those results to recent tests for tetryl, composition C-4, and composition A-3 obtained with the same equipment at the same facility. Appendix B gives the results of measurements of thermal properties of TSE-1005.

Differential Thermal Analysis

The DTA conducted on TSE-1005 produced the thermogram shown in Figure 6. This thermogram is essentially like one produced earlier by Thiokol[3/]. The first exotherm begins at approximately 300°F (149°C) and peaks at 363°F (184°C). As would be expected, the thermogram is practically identical to those obtained for PETN.

[3/]Thiokol Chemical Corp. Specialty Explosives Development, by W. O. Munson. Brigham City, Utah, Thiokol. (Publication No. 0373-73146B.)

TABLE 4. VTS and Sensitivity Test Results for TSE-1005 Compared to Three Commonly Used Explosives.

MATERIAL	VTS (100°C) ml/g/48 hr	HANDLING SENSITIVITY		
		IMPACT, cm	ABL FRICTION, lb	ELECTROSTATIC, J
TSE-1005	2.13	22	20/20 NF at 250	20/20 NF at 0.25
TETRYL	-	17-35	282-457	-
COMPOSITION C-4	0.05	-	-	-
COMPOSITION A-3	0.09	26-43	>700	20/20 NF at 0.25

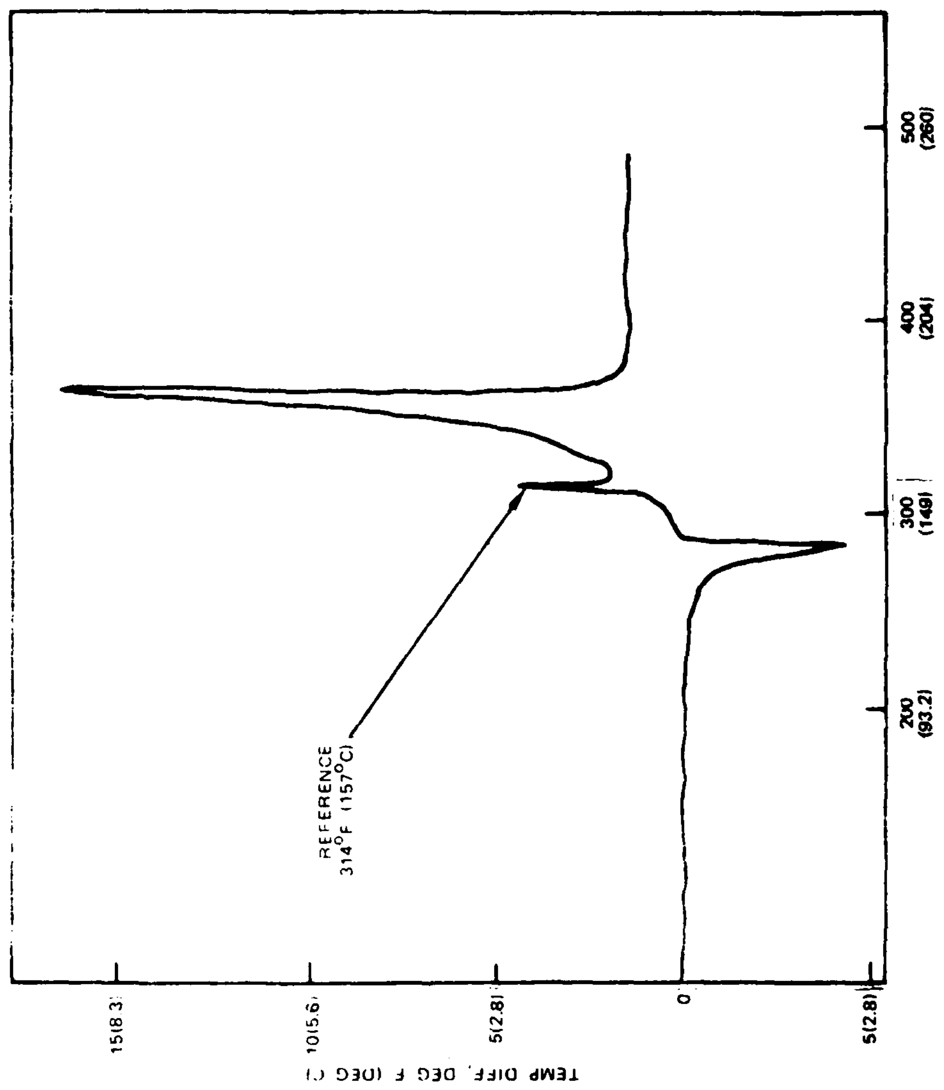

FIGURE 6. DTA Thermogram of TSE-1005.

CONCLUSIONS AND RECOMMENDATIONS

The test programs outlined at the beginning of this report were completed. These tests, combined with tests previously conducted by the manufacturers (as presented in Table 1), fulfill the characterization requirements specified by NAVSEA for the interim qualification of metal-working explosives. No unusual characteristics were found for either of these materials, and it appears that they can be safely handled using only those precautions normally used when handling military explosives of the same sensitivity.

Explosives as sensitive to impact ignition as Thiokol TSE-1005 have normally been labeled "booster explosives". Many of the characterization tests specified in NAVORD OD 44811 for booster explosives have not been conducted for this explosive. Also, the amount of gas evolved in the vacuum thermal stability test was slightly greater than the maximum amount specified in OD 44811 (2.13 ml/g/48 hr. vice 2 ml/g/48 hr.). Even so, since the self-heating test indicated satisfactory storage characteristics in small quantities at normal temperatures; and since this explosive has detonation characteristics needed for metal working and not readily available in other materials, it is recommended that this explosive be interim qualified for metal-working in small quantities.

Approval for Navy use for metal working is recommended for IRECO DBA-10HV with the condition that the fuel and oxidizer be shipped and stored separately. Under these conditions the fuel is a flammable material not normally considered explosive and the primary components of the oxidizer are water and an explosive that is already approved for service use. The slurry should not be mixed in quantities larger than needed for immediate use and should be detonated as soon as possible. These restrictions are recommended because large-scale gap tests have shown a relatively high shock sensitivity, slow cook-off or self-heating tests have not been conducted, and similar material's have been found to have poor stability.[4/]

[4/] Naval Weapons Center. Thermal Analyses Studies on Gelled Slurry Explosives (U), by J. M. Pakulak and Edward Kuletz. China Lake, Calif., NWC, May 1971. (NWC TP 5023, publication CONFIDENTIAL.)

DEPARTMENT OF THE NAVY
NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA 93555

IN REPLY REFER TO
3276/CMA:kdw
Reg. 3276-10-79
16 January 1979

MEMORANDUM

From: Carl Anderson (Code 3276)
To: Dan Harp (Code 3262)

Subj: Thermal Qualification/Safety of TSE-1005 Explosive System.

Encl: (1) Reduced Mettler T/A-2 charts:

a. Run 9-43-3, TSE-1005
b. Thiokol DTA
c. Run 2-74-3, PETN

(2) a. DSC Rate Runs, TSE-1005
b. Derived Rate Data

(3) Slow Cook-off Time-Temperature Runs.

(4) Slow Cook-off Summary

Ref: (1) Reg. 3262-115-78 of 5 Sept. 78 Dan Harp.

1. As a part of an interim qualification/safety program, Ref (1), for the Thiokol TSE-1005 sheet explosive, some of the thermal properties of this material were determined. The material consists of PETN with a binder and about 30% Copper Oxide as a detonation velocity control. Simultaneous differential thermal analysis, DTA, and thermogravimetric analysis, TGA, were run on the Mettler Instrument Co., Thermoanalizer-2, T/A-2, equipment. Chemical reaction rate parameters were obtained from a series of runs at varying rates on the Beckmann Instrument Corp., Differentral Scanning Calorimeter, DSC. Slow cook-off samples were prepared by cutting the supplied sheet material into 3" squares and stacking these squares to make a 3" cube. The cube was then wrapped in aluminum foil and inserted into a preheated oven and held until a reaction occurs.

2. Photo-reduced copies of the Mettler TA-2 charts are enclosure (1). A Thiokol Chemical Corp. DTA curve is included as enclosure (1) b, and a T/A-2 chart for a known sample of PETN is enclosure (1) c. The features of these charts are listed:

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Run No.	9-43-3	DTA, Thiokol	2-74-3
Sample	TSE-1005	TSE-1005	PETN
Wt. Sample	26.67 mg.	8.0 mg.	11.9 mg.
Heating Rate	3°C/min.	10°C/min.	3°C/min.
Endo Init. (M.P.)	136°C	125°C	140°C
1st Wt. loss (0.03 mg.)	135°C	——	143°C
Exo. Init.	145°C	149°C	145°C
Exo. Peak	179°C (Burst)	193°C	190°C
Wt. loss	17.5 mg.	——	11.1 mg.

3. The T/A-2 instrument also produces a trace that is the differential of the TGA trace, DTG. This trace is directly, reaction rate at that temperature in this dynamic system. A plot of log DTG vs. reciprocal absolute temperature should produce a line whose slope is E*/R, activation energy divided by the universal gas constant, R. Another technique available for the determination of chemical rate parameters is the Kissinger method of the variation of the peak temperature with scan rate. The method involves plotting the log of ϕ/T^2, heating rate over the square of the absolute temperature. Again, the slope of the line is E*/R. Enclosure (2) is a plot of these two methods. The reaction rate parameters determined by these methods are:

METHOD	SAMPLE	E*	A
Kissinger	TSE-1005	37.5 Kcal	4.5×10^{15} sec^{-1}
DTA/TGA	TSE-1005	40.5 Kcal	2.7×10^{16} sec^{-1}
DTA/TGA	PETN	44.0 Kcal	1.5×10^{18} sec^{-1}

The agreement among these results is good considering that relatively large errors are probable in reading the small deviations on the DTG trace.

4. Self-heating effects were determined by an isothermal, slow cook-off, SCO, method in which an instrumented sample was placed in a pre-heated oven and allowed to stand until a reaction occurred. Cubes, 3 inches on a side, made by stacking 3-inch squares of the sheet explosive, were instrumented with a thermocouple at the center of the cube, a second couple on the surface of the cube, and a third thermocouple in the aluminum foil, 3 layers, wrapping. The samples were monitored continuously using a Minneapolis-Honeywell multipoint recorder. The following runs were made using the 3-inch cubes:

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SCO No.	Oven Temp.	Time, Total (1)	Time, Equiv. (2)
343	100°C	ca. 75 da	6.5×10^6 sec.
353	105°C	ca. 700h	2.5×10^6 sec.
352	113°C	13h02m	3.16×10^4 sec.
342	120°C	8h12m	1.29×10^4 sec.
341	133°C	5h10m	3.6×10^3 sec.

(1) Total time from insertion of cold sample into oven.
(2) Equiv. time+ time at oven temperature corrected for the amount of reaction that occurred during the warm-up period.

Enclosure (3) contains the various time-temperature plots for these SCO runs. This material, TSE-1005, exhibited a series of anoymalies in behavior; such as: (1) The DTA/TGA traces suggested an initial experiment at about 135°C, the first weight loss temperature. In SCO-341 at 133°C, the sample did not even reach the oven temperature before reacting. (2) At 113°C, SCO-352, a normal looking cookoff occurred 13 hours after being placed in the oven. (3) At 105°C, SCO-353, the center temperature went above the oven by about 2°C, held for 10 hours, and then cooled back to the oven temperature. Subsequently, the center temperature rose normally to about 5°C above the oven at about 500 hours, held for 200 hours, and then cooled again. (4) At 100°C, no apparent reaction occurred at all in 75 days. Since the ovens and spaces were needed for other priority work, both samples were burned out by raising the oven temperature until a reaction occurred. In both cases, the ovens were first allowed to cool and the samples inspected before burning off the explosives. The original, somewhat flexible material had fuzed to a solid block, had taken on a spherical shape, and had a greenish-black color. At the higher temperatures, the copper oxide present apparently acted as the oxidizing agent for the organic materials remaining and produced a red matrix of copper metal.

5. Extrapolations and conclusions. Enclosure (4) is a plot of the logarithm of time-to-reaction vs. the reciprocal of the absolute temperature of the oven. All of these points and ranges are for the three-inch cubes that were assembled from 3-inch square pieces of this sheet explosive. These data would indicate that, for 3-inch cubes, temperatures below 100°C would be safe indefinitely. The PETN explosive in the material is decomposing, but slowly enough to produce no temperature rise in the material. The behavior at 105°C suggests that the second reaction removed most if not all of the PETN. In larger sizes, such as in storage/shipping

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boxes of the sheet material, these reaction should occur at lower temperatures and/or longer times. It is the opinion of the writer, that this material should qualify under the self-heating requirements of OD-44811 in the size of the shipping container.

CARL M. ANDERSON
Code 3276

Copy to:
327
3276
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APPENDIX II

4033: CJN: eak
2300
13 Oct 1976

MEMORANDUM: 76-2172

From: 4033
To: 852

Subj: Bi-metallic Bulkhead Penetration, Test Results of

Ref: (2) Memorandum 852: TRM: kp/423, dated 22 Sept 1976

Encl: (1) Photographs numbered 1 to 20.

1. This memorandum presents the results of test requested in reference (a), memorandum 852. Two tubular specimens were received, one of steel, about 4 1/2 inches long, and the other of a Ni-Cu alloy, about 3 inches long, each having an aluminum collar welded near the central section, and approximately half of each specimen painted. The specimens were first photographed as received, photograph (1), steel and (2), Ni-Cu, of enclosure (1).

2. The specimens were subjected to a 20% salt spray bath for 100 hours and photographed. The unpainted steel surface, photograph (3), showed moderate corrosive attack and the painted surface showed very slight attack. The painted surfaces of the Ni-Cu and the aluminum showed no attack, as can be seen in photograph (4). The unpainted surface of aluminum showed slight attack and the unpainted surface of the Ni-Cu showed none.

3. The specimens were subjected to 100 more hours of salt spray bath (totaling 200 hours) and again photographed. The painted surface on the steel, photograph (5), was strongly attacked. The unpainted surface on the steel was very strongly attacked and the aluminum moderately so. The painted surface on the Ni-Cu tubing, photograph (6), showed very little attack; the unpainted Ni-Cu was very slightly attacked. The painted surface on the aluminum collars showed a few places of attack. Photographs near 7.5X magnification that were taken near the weld seams of the unpainted aluminum collars on both steel, photograph (7), and the Ni-Cu specimen, photograph (8), showed considerable pitting corrosion in the aluminum.

4. The paint was then removed from the specimens and photographs again taken. The steel was attacked both with and without the paint, photograph (9). It appeared that the Ni-Cu, photograph (10), was relatively free of attack both with and without the paint coating. The aluminum was protected by the paint except near the weld seam, where some corrosion was observed.

5. The specimens were then sectioned through the unpainted regions and the regions from which the paint had been removed. The steel specimen was sectioned a third time near external corrosion attack because a previous section had shown cracking that was possibly non-typical. The surfaces were rough polished (through 600 grit paper) and photographed near 7.5X magnification, with a linear scale included in each picture, each smallest division of which was 0.025 inch.

6. The painted steel specimen, right end of weld, photograph (11), and left end of weld, photograph (12), showed no surface attack at the section, but the weld bond showed some imperfections. The unpainted steel specimen was sectioned twice. One section, photographs (13) and (14), showed severe pitting in the aluminum collar at and just above the weld seam. The other section, photographs (15) and (16), showed cracking for about 5/16 of an inch and other points of corrosion within the material near and above the weld seam, extending into the collar.

7. The section through the previously painted protion of the Ni-Cu specimen, photographs (1) and (18), showed no surface corrosion attack, but did exhibit very poor weld bonding. The unpainted Ni-Cu specimen section, photographs (19) and (20), showed corrosion attack in the aluminum surface near the weld but none right at the seam.

Bernard Brown

BERNARD BROWN

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4033 (2)

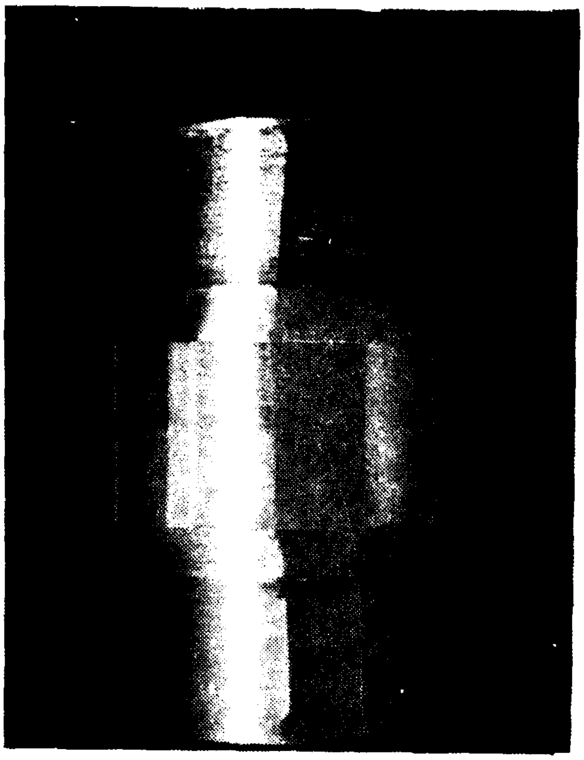

Fig. 1. Tubular Steel Specimen, aluminum collar, about half painted, as recived.

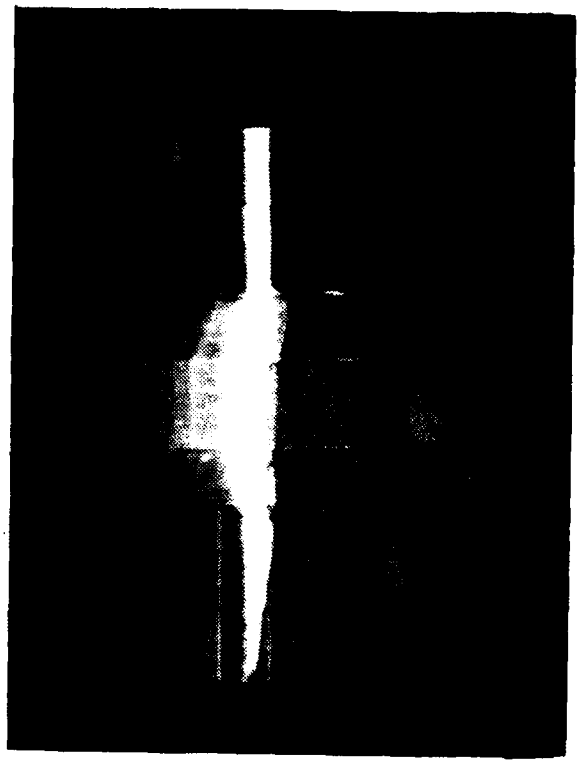

Fig. 2. Tubular Ni-Cu Specimen, aluminum collar, about half painted, as recived.

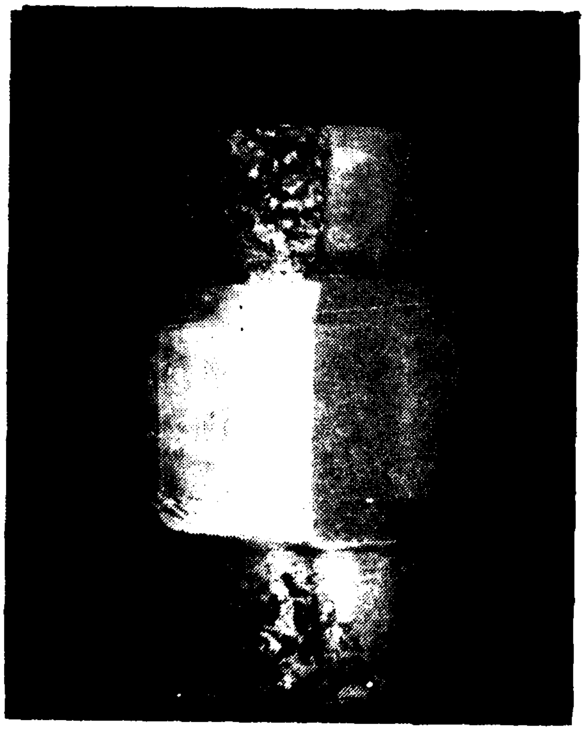

Fig. 3. Steel Specimen after 100 hours of 20% salt spray bath.

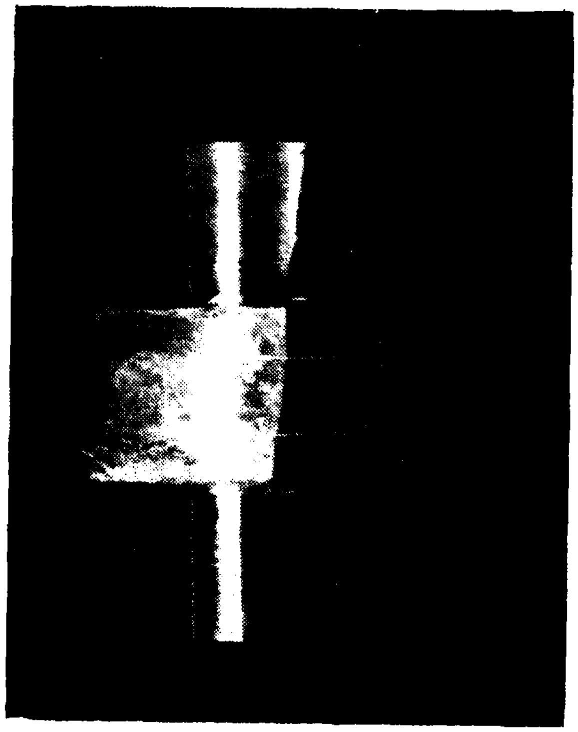

Fig. 4. Ni-Cu Specimen after 100 hours of salt spray.

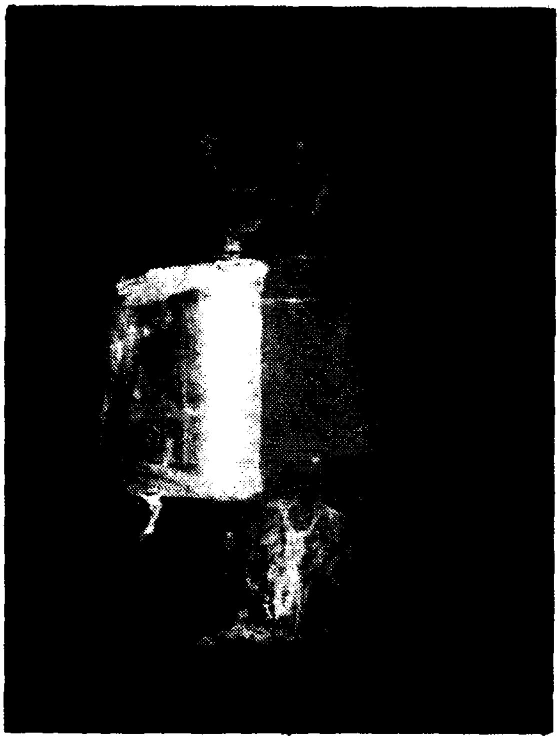

Fig. 5. Steel Specimen after 200 hours of salt spray.

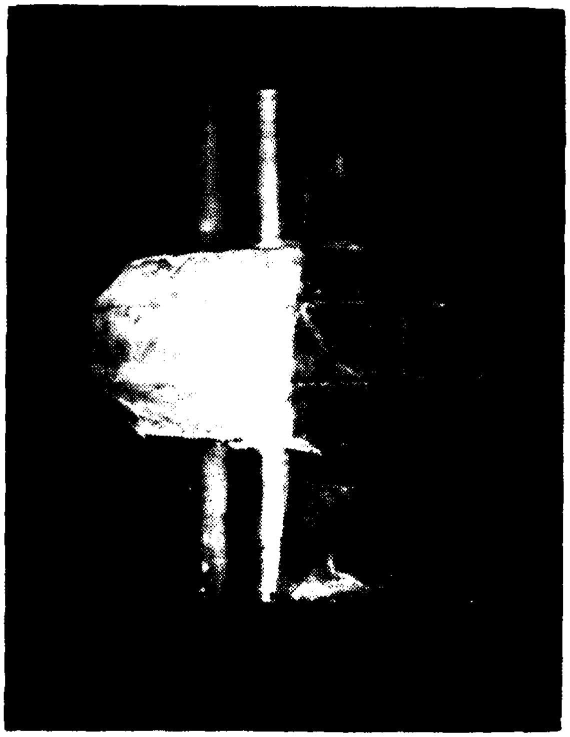

Fig. 6. Ni-Cu Specimen after 200 hours of salt spray.

Fig. 7. Steel Specimen, unpainted, near aluminum collar weld seam, 7.5 X.

Fig. 8. Ni-Cu Specimen, unpainted, near aluminum collar weld seam, 7.5 X.

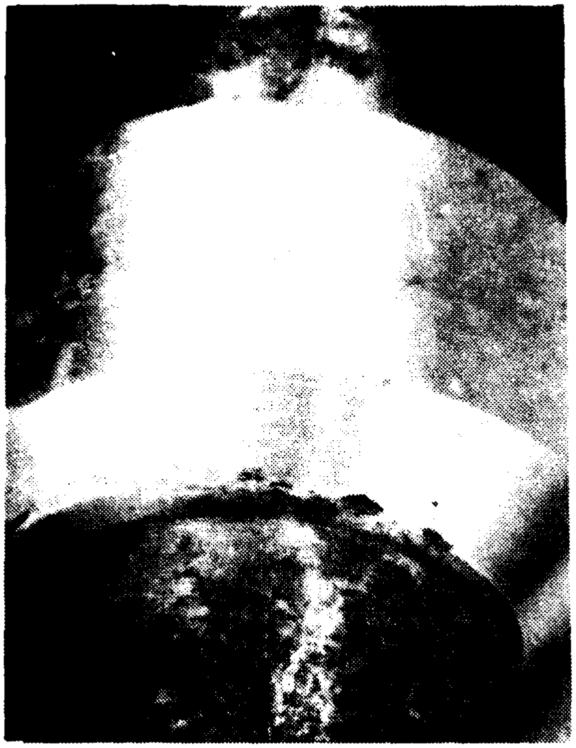

Fig. 9. Steel Specimen, unpainted and paint-removed regions.

Fig. 10. Ni-Cu Specimen, unpainted and paint-removed regions.

Fig. 11. Steel Specimen, painted, left end of section, 7.5 X

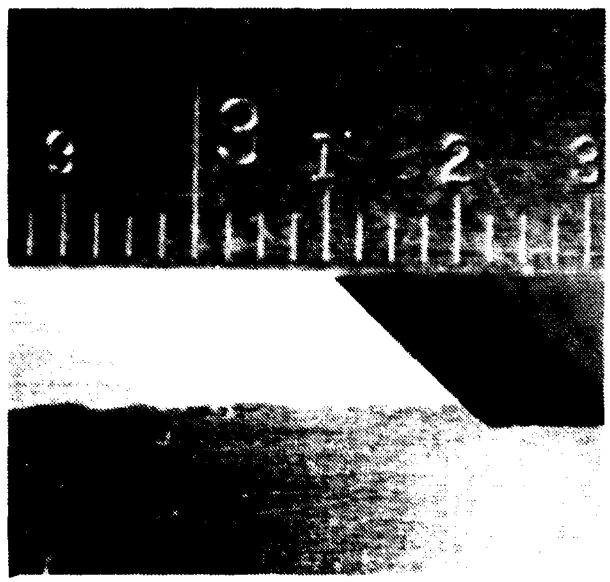

Fig. 12. Steel Specimen, painted, right end section, 7.5 X.

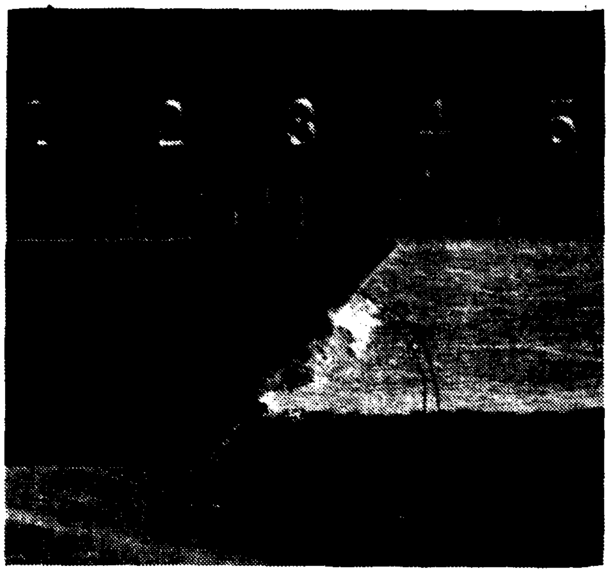

Fig. 13. Steel Specimen, unpainted, left end of section, 7.5 X.

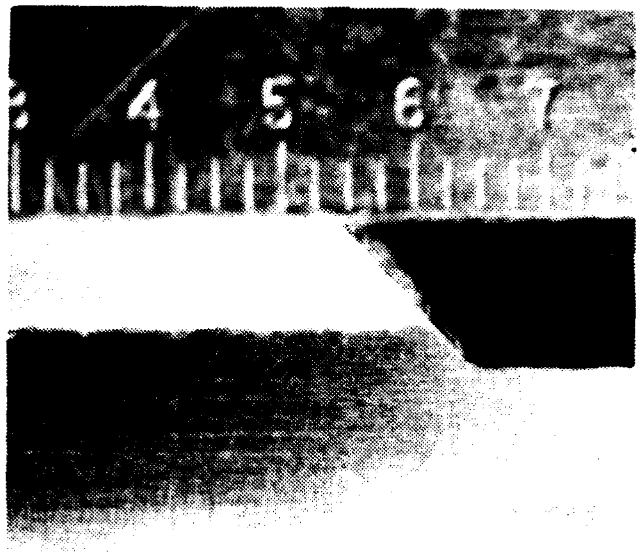

Fig. 14. Steel Specimen, unpainted, right end of section, 7.5 X.

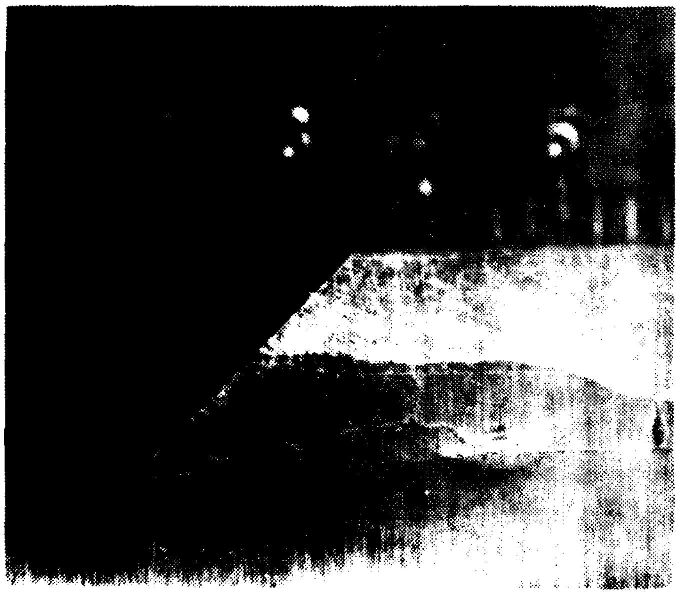

Fig. 15. Steel Specimen, unpainted, left end of section (with crack), 7.5 X.

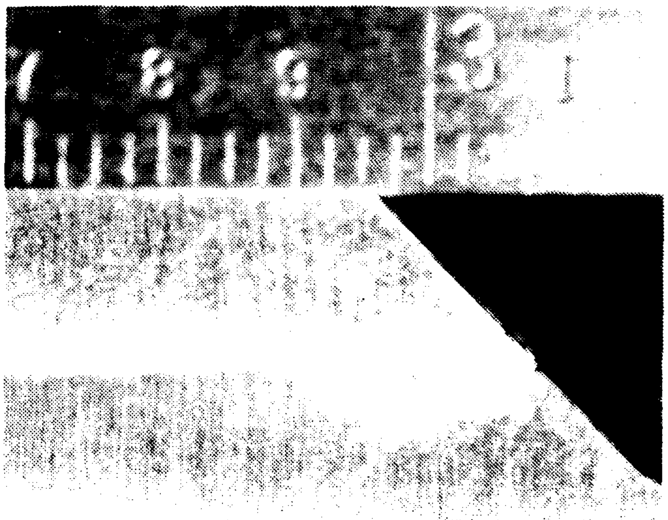

Fig. 16. Steel Specimen, unpainted, right end of section (with paint imperfections), 7.5 X.

Fig. 17. Ni-Cu Specimen, painted, left end of section, 7.5 X.

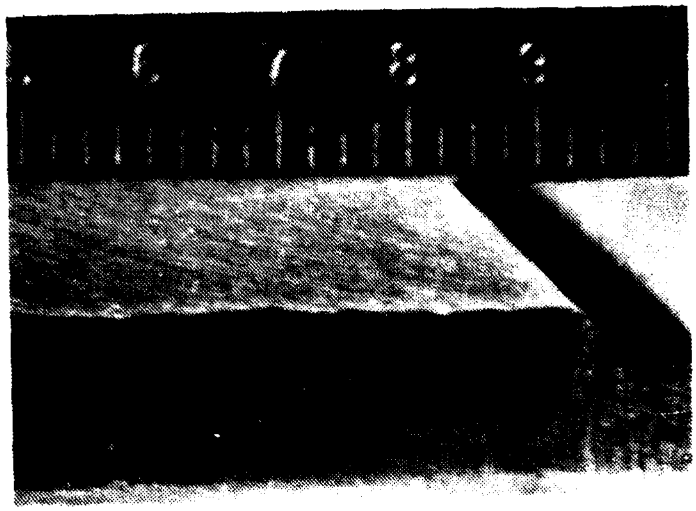

Fig. 18. Ni-Cu Specimen, painted, right end of section, 7.5 X.

Fig. 19. Ni-Cu Specimen, unpainted, left end of section, 7.5 X.

Fig. 20. Ni-Cu Specimen, unpainted, right end of section, 7.5 X.

APPENDIX III

PIPING STRUCTURAL PENETRATIONS FATIGUE STRENGTH EVALUATION

Performed For:

Naval Ordnance Station
Louisville, Kentucky

Report No. TH-3193

Contract No.: N00197-78-C-0189(J)

Respectfully Submitted

Cincinnati Testing Laboratories, Inc.
Cincinnati, Ohio

May, 1979

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PHOTOGRAPHS (CONT'D.)

1.0 INTRODUCTION

The strength and integrity of structural members subjected to cyclic loading can be very dependent upon stress concentrations and discontinuties. Shipboard piping penetrations that pass through a hull structure represent a discontinuity in the structure and can cause severe changes in the structures strength. This can result in premature failure of the structure and/or loss of integrity of the piping system under shipboard loading conditions. It is, therefore, very important to the design and application of the penetration concepts that basic test data be developed that correlate the effects of stress concentrations and different types of hull penetrations under shipboard cyclic loading conditions.

This report describes the results of fatigue strength tests conducted on large panels with and without piping penetrations and high cycle fatigue tests conducted on subscale specimens with and without piping penetrants. Section 2.0 describes the testing on the large panel specimens and section 3.0 describes the high cycle fatigue tests of the subscale specimens.

2.0 FATIGUE STRENGTH EVALUATION OF PIPING STRUCTURES

2.1 PURPOSE/SCOPE

The purpose of this portion of the program was to conduct fatigue tests on large panel specimens of two design concepts for piping penetrations through the hull structure. The two concepts were:

A. Bolted flange
B. Explosive-Bonded sleeve

The effect was primarily directed towards assessing the relative influence of the two types of penetrations on load carrying capabilities of the hull structure. Comparative data is provided for a basic hull material specimen, a single hole specimen, and for the two penetrant concepts.

2.2 SPECIMEN DESCRIPTION

Each test panel specimen consisted of a 3/16" thick 5456 aluminum alloy plate with or without a structural penetration for 2" IPS 304 stainless steel pipe located at the center of the plate element. Doublers were attached to both faces of each test plate in the grip areas to eliminate specimen failure through the grip attachment. The test panel configuration is shown by Figure 1, the bolted flange penetration is shown in Figure 2 and the explosive bonded sleeve penetration in Figure 3. The explosive bonded sleeve penetration was welded into the aluminum panel by Rohr Marine Corp., using standard shipboard welding procedure. The welding caused warpage in the test panel which resulted in non-uniform strains during test and likely reduced the cyclic life.

2.3 TEST DESCRIPTION

The basic test condition used for each test was an axial tension-tension fatigue cyclic loading. Duration of the testing on each specimen was 1 x 10^6 load cycles or specimen failure, whichever occurred first. Fatigue testing on each specimen was conducted at constant alternating stress and constant maximum cyclic load at a cycling rate of 2 Hz. The load cycling wave form was sinusoidal. For each test specimen, the specific maximum and minimum cyclic stress level across the full reduced section area away from the penetration was 13,500 psi and 500 psi, respectively. The specimen was frequently inspected for evidence of failure initiation while fatigue cycling was in progress. In addition, cycling was interrupted at 5,000, 10,000, 20,000, 50,000 load cycles and every 50,000 load cycles thereafter to thoroughly examine the specimen and to record strain gage data. Inspection for cracks, while cycling was interrupted, was conducted with the maximum cyclic load statically maintained on the specimen to improve crack visibility.

2.4 TEST SET-UP AND INSTRUMENTATION

The panel specimen fatigue testing was conducted in an MTS closed loop low cycle fatigue machine. An analog sine wave generator control system was utilized to produce sinusoidal loading on the test specimens.

Commercial foil type uniaxial strain gages were installed on each specimen and recorded during a static load cycle at the start of test and at the intervals specified above for crack inspection. All gages were aligned to measure strain in the specimens axial direction.

2.5 TEST SEQUENCE

The following specimens were tested in the previously described manner:

a. One panel specimen without penetration preparation.

b. One panel specimen with penetration preparation. This specimen had a 2.875 inch diameter hole to simulate the preparation required for the explosive bonded sleeve penetration.

c. One panel specimen with bolted flange penetration.

d. One panel specimen with explosive bonded sleeve penetration.

Photographs 1, 2, 3 and 4 show each of the above four specimens set-up for testing in the MTS test machine.

2.6 TEST RESULTS

2.6.1 PANEL SPECIMEN WITHOUT PENETRATION PREPARATION

This panel specimen was set-up for test as described above and instrumented with eight strain gages located as shown in Figure 4. The specimen was subjected to the full 1×10^6 load cycles with a maximum load of 41,810 pounds. This load provided the specified test conditions. Table I provides a tabulation of the recorded strain data and inspection comments as a function of the number of load cycles.

Strains were uniform at all gage locations showing that the gripping attachment was successful in evenly distributing the load. During the test there was no indication of failure, yielding or crack initiation.

2.6.2 PANEL SPECIMEN WITH PENETRATION PREPARATION

This panel specimen was prepared with a 2 7/8 inch diameter hole at the center of its' gage section to simulate the penetration preparation for the explosive bonded sleeve penetration. It was instrumented with nine (9) strain gages as defined in Figure 5. The gage locations were selected to check load distribution across the specimen, strain build-ups adjacent to the hole, and face-to-face bending.

The specimen was subjected to a maximum cyclic load of 41,702 pounds. Table II provides a tabulation of the recorded strain data and inspection comments as a function of the number of load cycles. The strain data shows uniform side to side and through the thickness strains with changes in strains across the section, reflecting the distributional effects from the center hole. The distributional effect causes lowered strains at the center line of the specimen, above and below the hole, with a build-up of high strain at the sides of the hole. During testing the highly strained regions at the side of the hole had some reduction in strain during the first 100 cycles while the location immediately adjacent to the hole at the side had an increase in strain in the last half of the cyclic life. Failure occurred after 141,790 cycles.

Photograph 5 shows this specimen following test.

2.6.3 PANEL SPECIMEN WITH BOLTED FLANGE PENETRATION

This panel specimen was prepared as shown in Figure 2 and set up for test as described previously. It was instrumented with ten strain gages as shown in Figure 6. The specimen was subjected to a maximum cyclic load of 41,378 pounds to provide the specified test conditions. Failure occurred after 80,680 cycles. Table III provides a tabulation of the recorded strain data and inspection comments as a function of the number of load cycles. The strain data shows reasonably equal side to side strains, some slight signs of bending from the back to back gages (gages 3 and 4), and distributional effects from the hole and flange arrangement.

The maximum recorded strains at the inner surface of the hole are less than those measured for the specimen with only the hole. This indicates that the flange was carrying a portion of the loading. The only strain change evident prior to failure was a reduction in strain on gage number 7. Photograph 6 shows this specimen following test.

2.6.4 PANEL SPECIMEN WITH EXPLOSIVE BONDED SLEEVE PENETRATION

This panel specimen was prepared as shown in Figure 3 and set up for test as described above. It was instrumented with eight strain gages as defined in Figure 7. The specimen was subjected to a maximum cyclic load of 41,756 pounds to provide the specified test conditions. Failure occurred after 96,860 cycles. Table IV provides a tabulation of the recorded strain data and inspection comments as a function of the number of load cycles. The strain data shows equal side to side loading and unequal face to face loading. Strains were approximately 50% higher on one face than the other. This was due to distortion of the panel which occurred during welding of the penetration into the specimen. Strains were highest in the region of gages 1 and 2, directly above the penetrant, but no large distributional effects were seen.

A relatively large drop in strain occurred at each of the 3 gages near the penetrant during the first 5000 cycles. This may be indicative of a localized increase in strains at some locations not monitored by gages.

Crack initiation was observed at 81,790 cycles. This consisted of a crack in the weld in one side of the specimens' centerline. By 84,260 cycles the crack had extended across the top of the weld, by 88,840 cycles the crack was visible on the opposite side of the specimen and at 96,860 cycles the specimen failed. Table IV provides a tabulation of the recorded strain data and inspection comments. Table V provides initial strain data versus step loading revealing the strain irregularities that resulted from extreme warpage that occurred during welding of the penetrant. Photograph 7 shows the specimen following test.

3.0 HIGH CYCLE FATIGUE STRENGTH EVALUATION OF SUBSCALE PIPING STRUCTURE PENETRATIONS

3.1 PURPOSE/SCOPE

The purpose of this portion of the program was to conduct high cycle fatigue (HCF) subscale specimen tests to determine the influence of the explosive bonded sleeve penetration concept on the load carrying capability of the hull structure over a broad range of stress loadings. Comparative S-N curves were determined for the basic hull material, for specimens with an explosive bonded sleeve penetration, and a similar specimen as the penetration specimen but with only a circular hole discontinuity.

3.2 SPECIMEN DESCRIPTION

Seven or more subscale specimens with each of 3 configurations were tested. All specimens were machined from 3/16 inch thick 5456 aluminum plate. The three configurations were: 1) dogbone material specimen, 2) explosive bonded sleeve penetration specimen with 3/4 inch IPS 304 stainless steel pipe and 3) specimens with only a circular hole at the center of the gage section. The dogbone material specimen configuration is defined by Figure 8 and the explosive bonded sleeve and circular hole specimen configurations by Figure 9.

The explosive bonded sleeve penetrations were welded into the aluminum specimens by Rohr Marine Corporation. These specimens were severely warped during welding which likely resulted in a reduced cyclic life.

3.3 TEST DESCRIPTION

All specimens were tested in axial tension-tension fatigue in a Satec high cycle fatigue test machine at 30 Hz. The applied max stress for each test was selected to provide an S-N curve over the range of 10^4 to 10^7 cycles. Cycling was interrupted at frequent intervals and the specimen inspected for cracks. No strain gage instrumentation was employed during this testing. Photograph 8 shows a HCF dogbone specimen set-up for test. Photograph 9 is the hole only specimen and Photograph 10 is the HCF explosive bonded sleeve set-up.

3.4 TEST RESULTS

Eight subscale dogbone material specimens were tested over a stress range of 20,000 to 40,000 psi and had a cyclic life of from 4×10^4 to runout at 1.34×10^7 cycles. Two additional dog bone specimens having the full 3/16 inch plate thickness were also tested at 30,000 psi for comparison to the subscale thickness data. Table VI provides a summary of this test data. Figure 10 provides an S-N curve for the data. The full thickness 3/16" specimens provided slightly higher fatigue strength. Photograph 11 shows the post test specimens.

Seven subscale explosive bonded sleeve penetration specimens were tested over a stress range of 4000 to 20,000 psi and had a cyclic life of from 10^4 to runout at 10^7 cycles. Table VII provides a summary of this test data and Figure 11 provides an S-N curve for the data. The 10^6 cycle strength of the penetration specimens is approximately 25% of that of the basic hull material as determined by the subscale dogbone specimens. Photograph 12 shows the post test specimens.

Seven subscale specimens with a center hole were tested over a stress range of 6500 to 20,000 psi and had a cyclic life of 1.2×10^4 to runout at 1.1×10^7 cycles. Table VIII provides a summary of the test data and Figure 12 provides an S-N curve for the data. The 10^6 cycle strength of these specimens is approximately 35% of that of the basic hull material and approximately 30% greater than that for the specimens with penetrants. Photograph 13 shows the post test specimens.

A comparison of the subscale data and the large panel data show reasonable correlation and indicates that the subscale data could be used to predict the S-N strength curve for the larger structures.

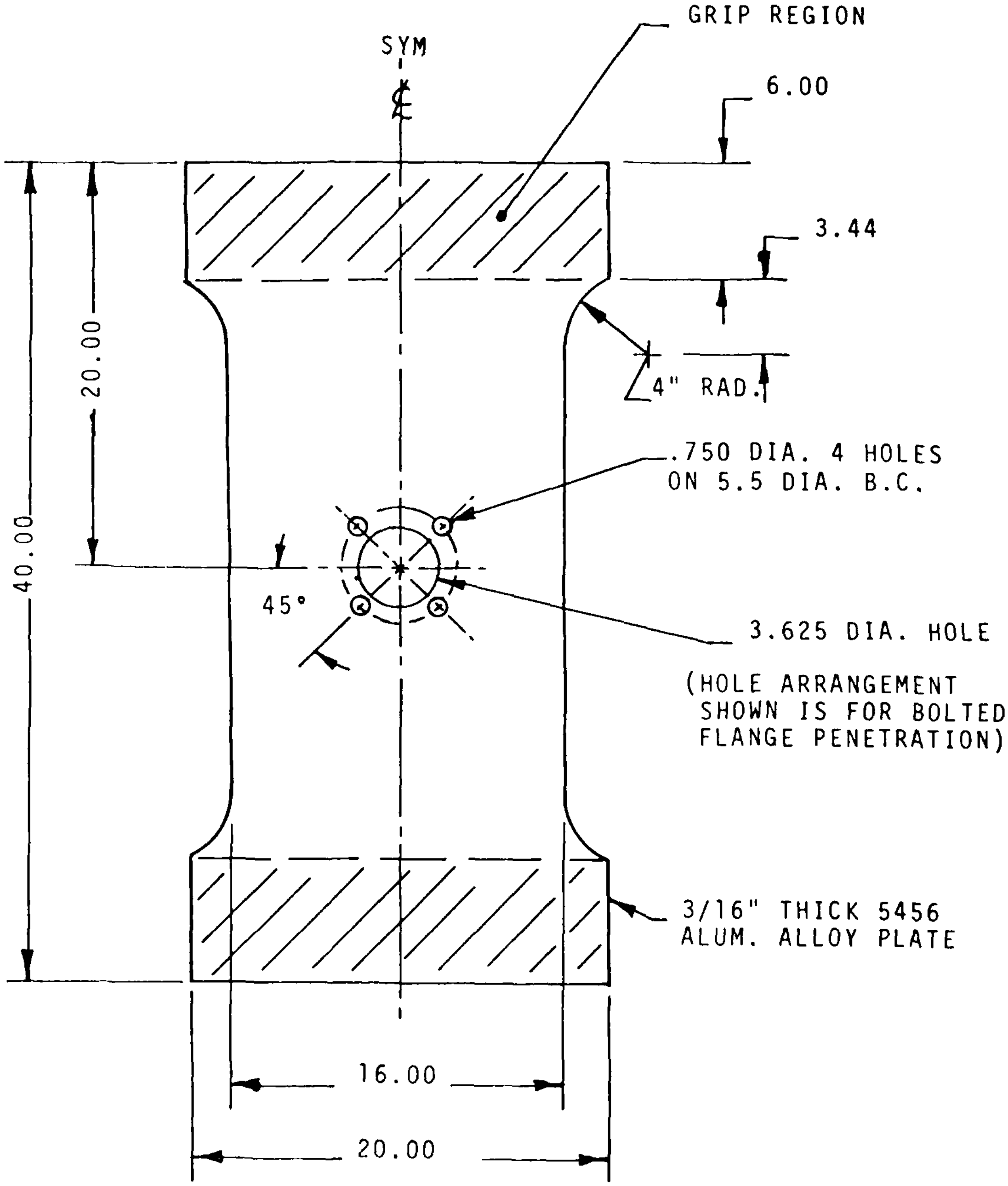


FIGURE 1 TEST PANEL DESIGN

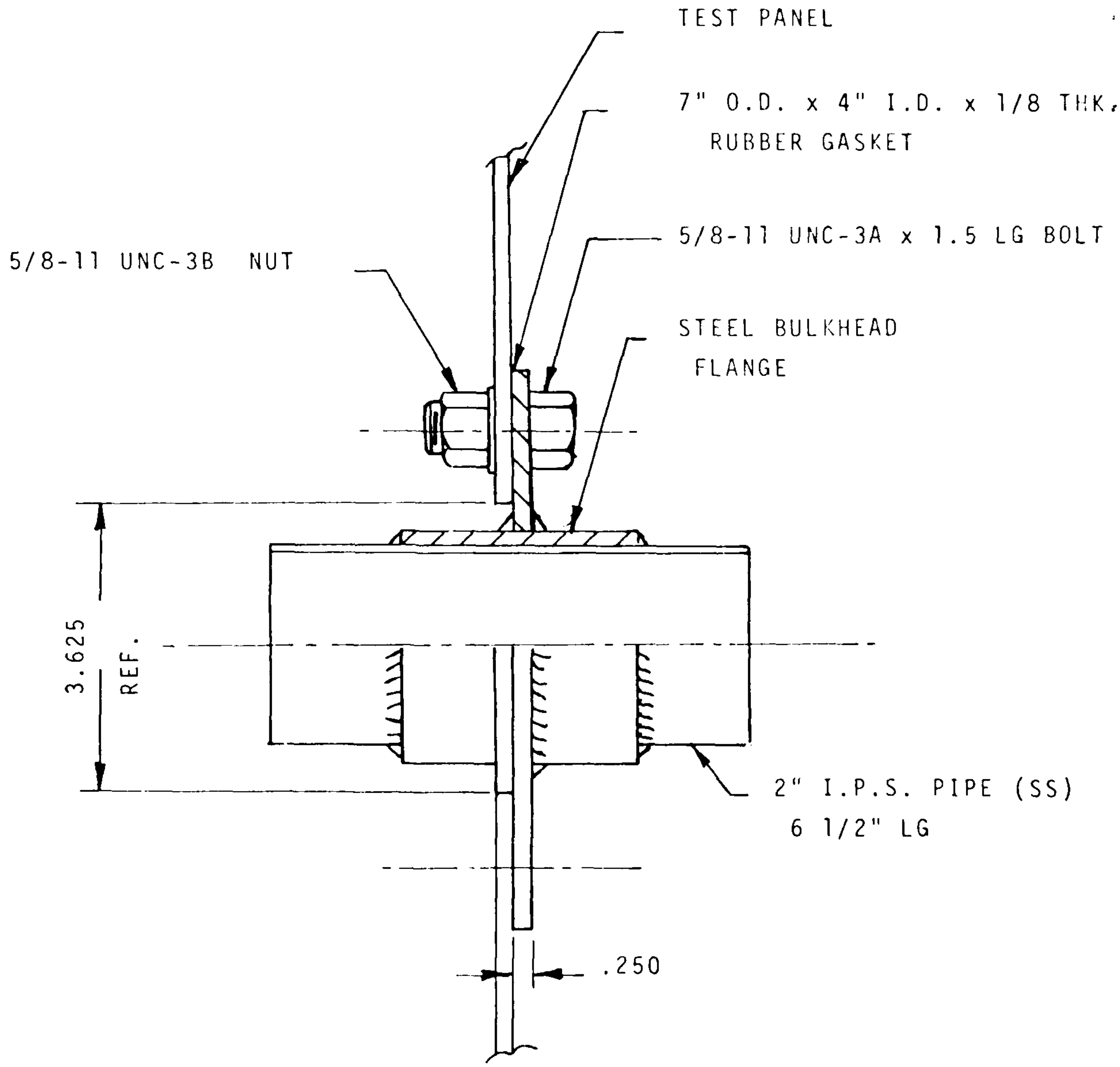


FIGURE 2 BOLTED FLANGE PENETRATION CONFIGURATION

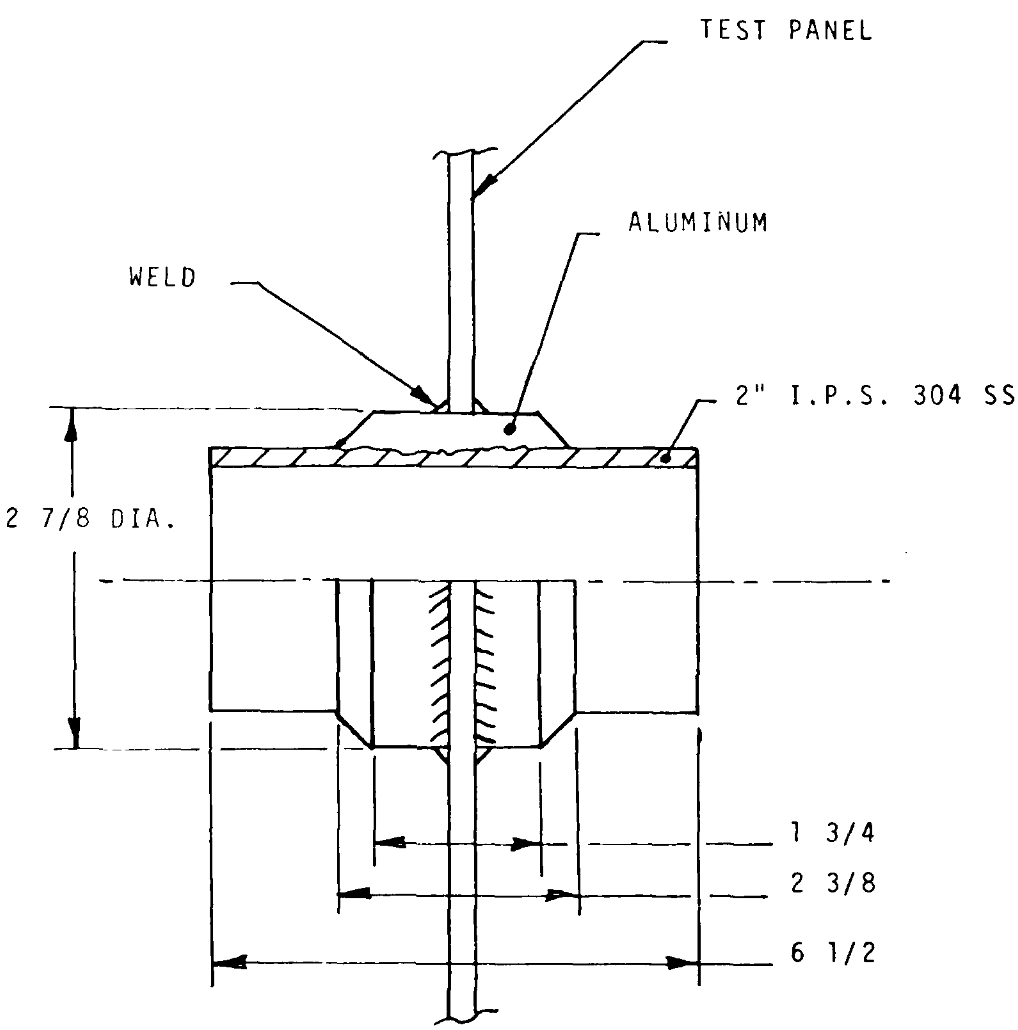


FIGURE 3 EXPLOSIVE BONDED SLEEVE PENETRATION CONFIGURATION

Strain Gage Type:
Bean BAE-13-125AA-350TE

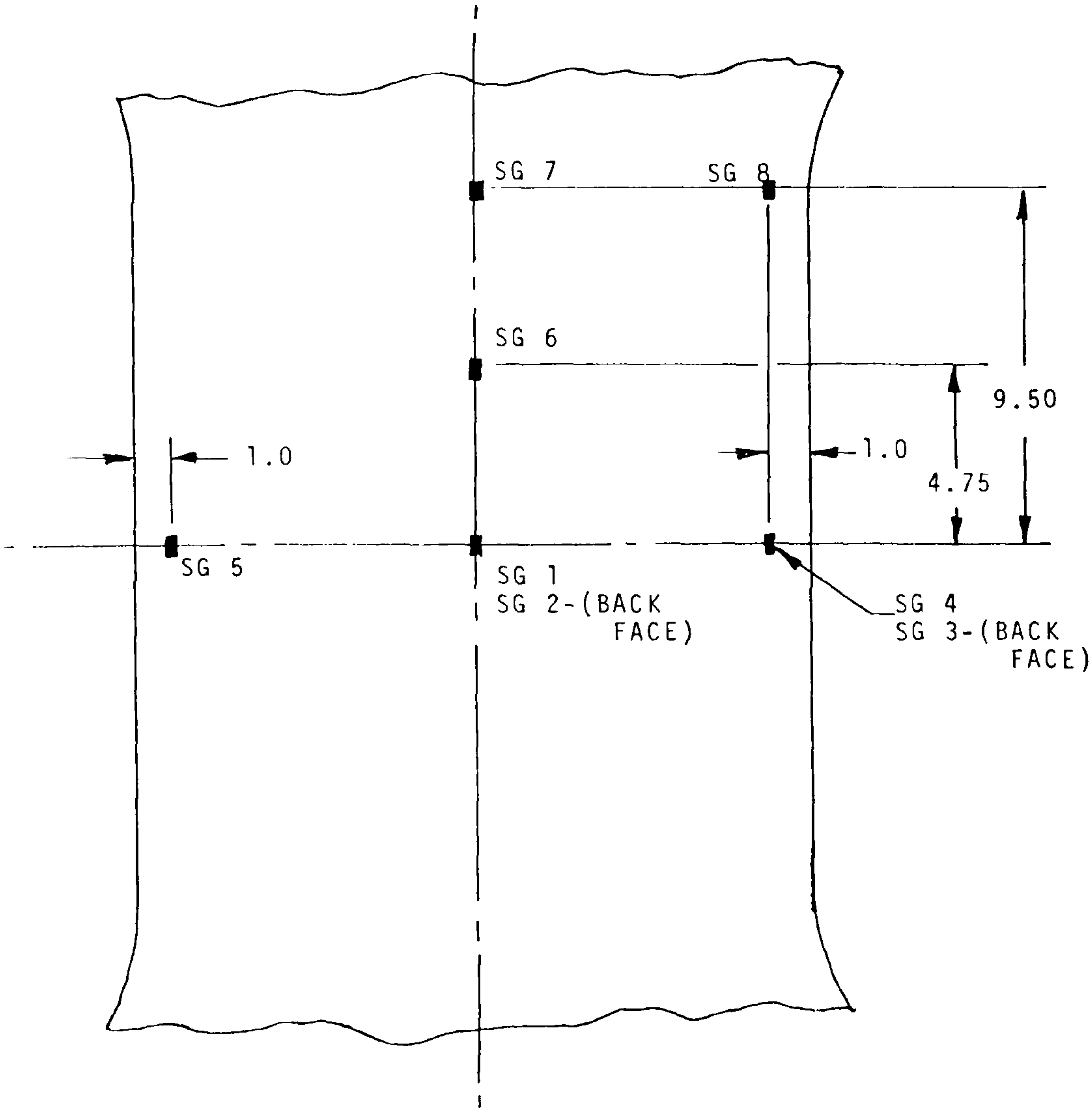


FIGURE 4 STRAIN GAGE LOCATIONS ON PANEL SPECIMEN WITHOUT PENETRATION PREPARATION

Strain Gage Type:
Bean   BAE-13-125AA-350TE

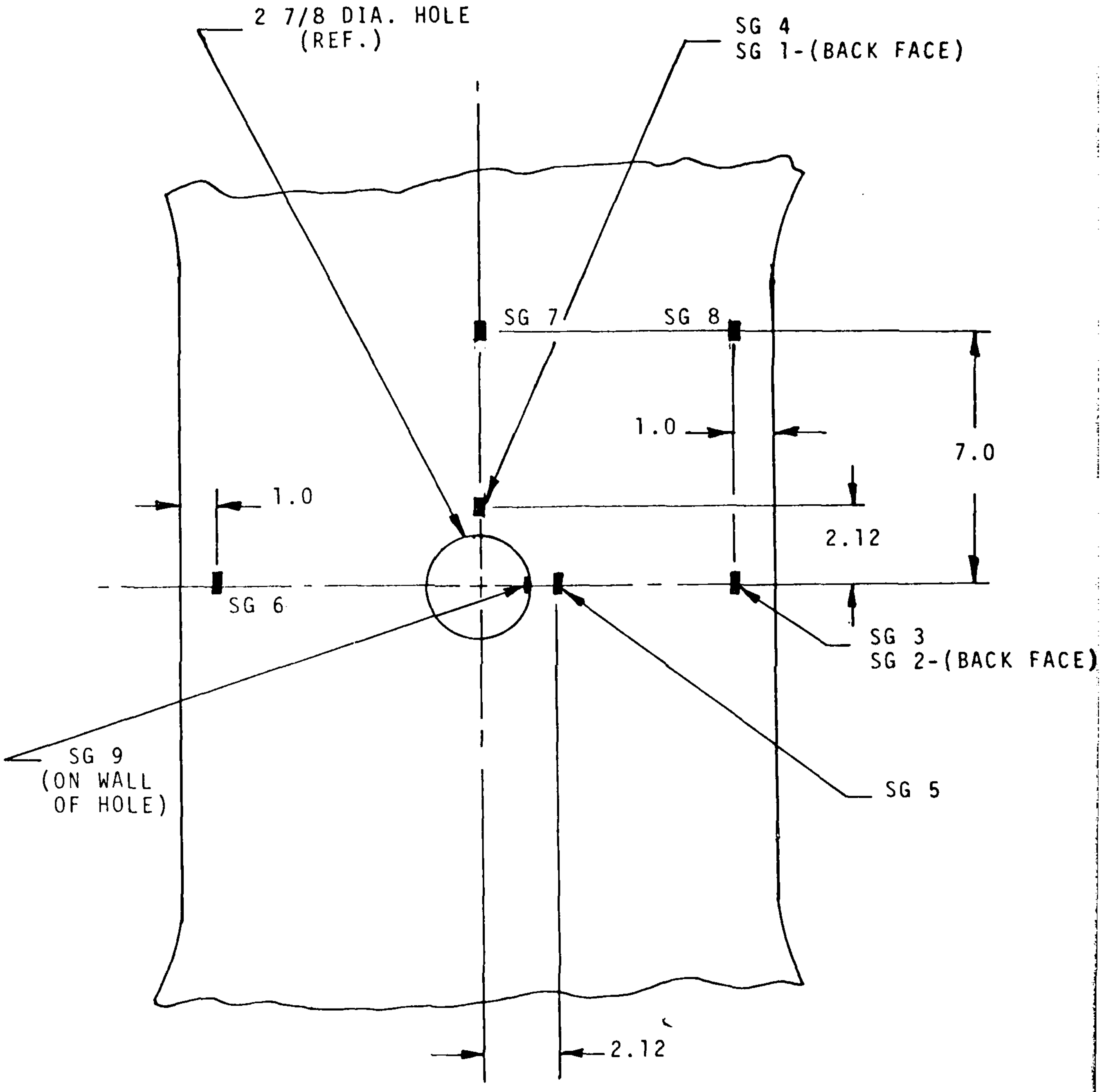


FIGURE 5   STRAIN GAGE LOCATIONS ON PANEL SPECIMEN WITH HOLE PENETRATION PREPARATION

Strain Gage Type:
Bean BAF-13-125AA-350TE

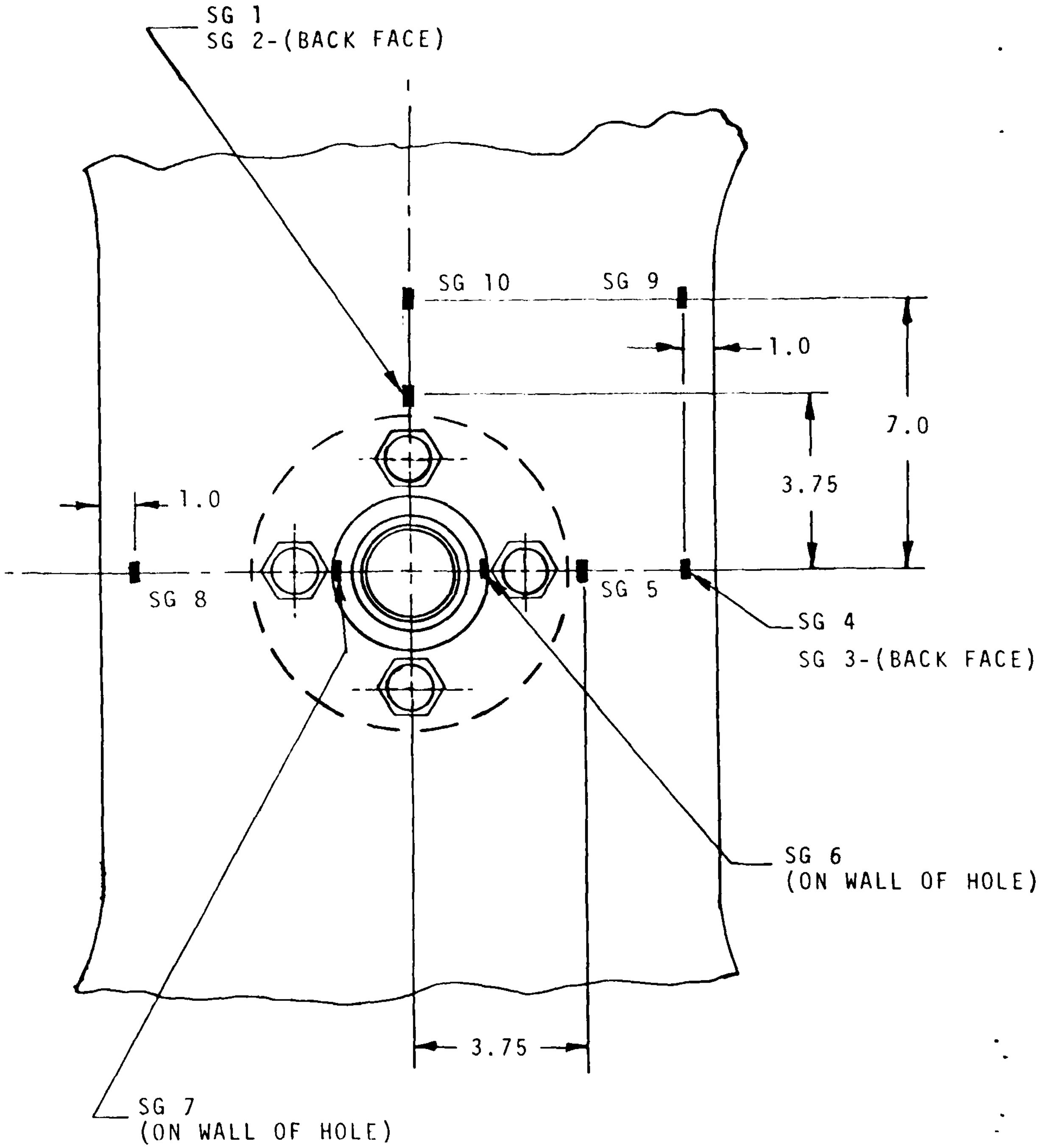


FIGURE 6 STRAIN GAGE LOCATIONS ON PANEL SPECIMEN WITH BOLTED FLANGE PENETRATION

Strain Gage Type:
Bean BAE-13-125AA-350TE

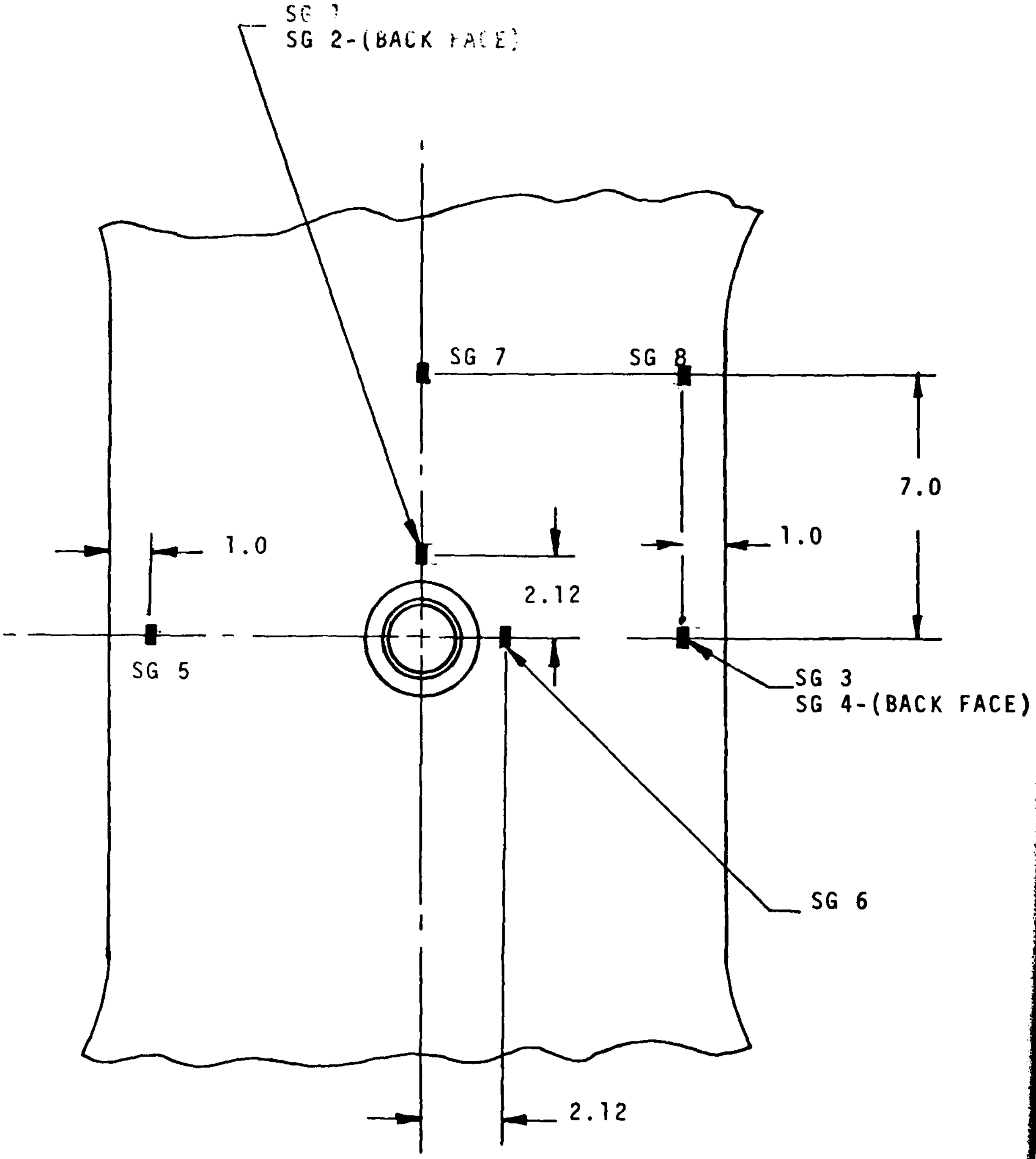


FIGURE 7 STRAIN GAGE LOCATIONS ON PANEL SPECIMEN WITH EXPLOSIVE BONDED SLEEVE PENETRATION

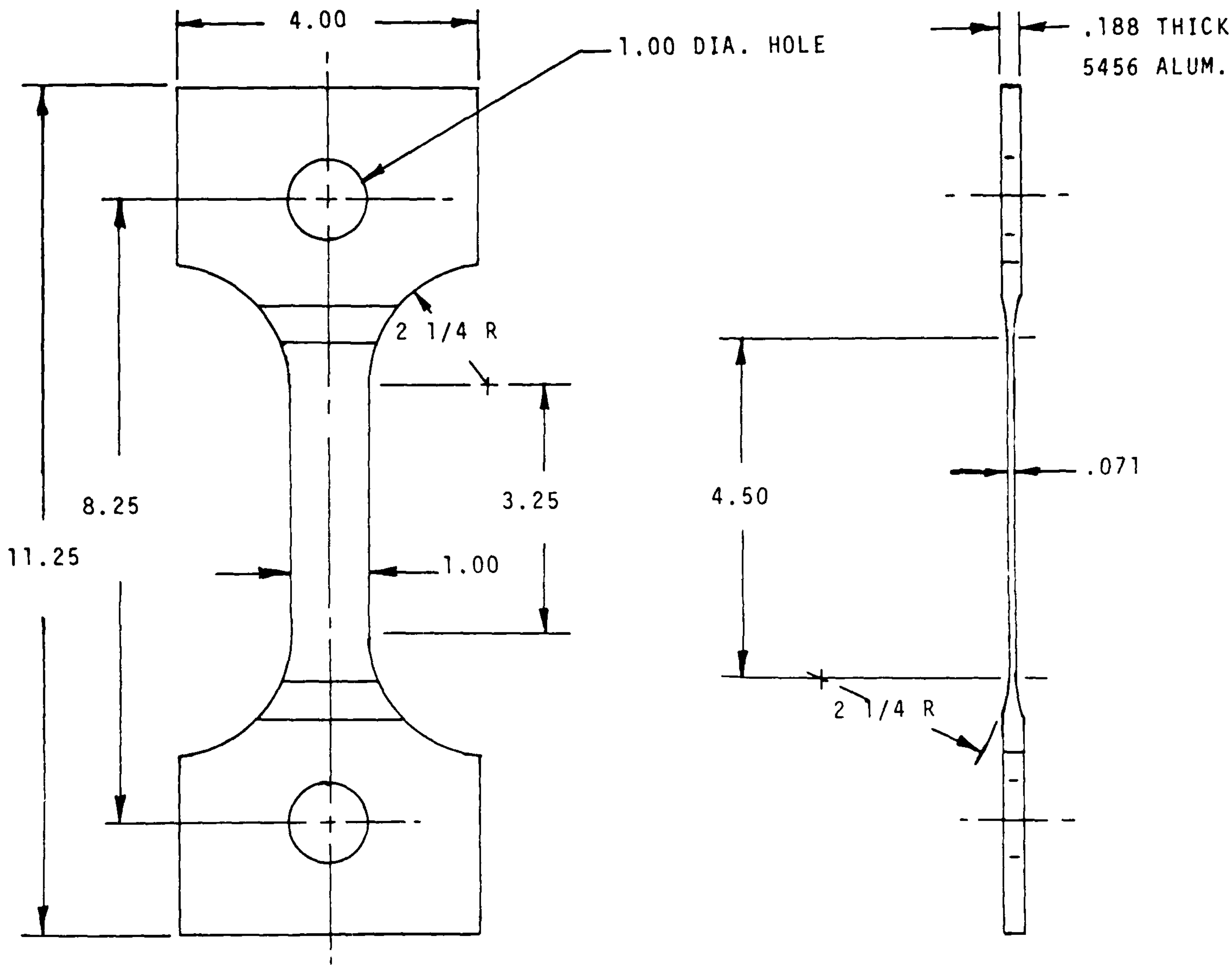


FIGURE 8 HIGH CYCLE FATIGUE DOGBONE MATERIAL SPECIMEN CONFIGURATION

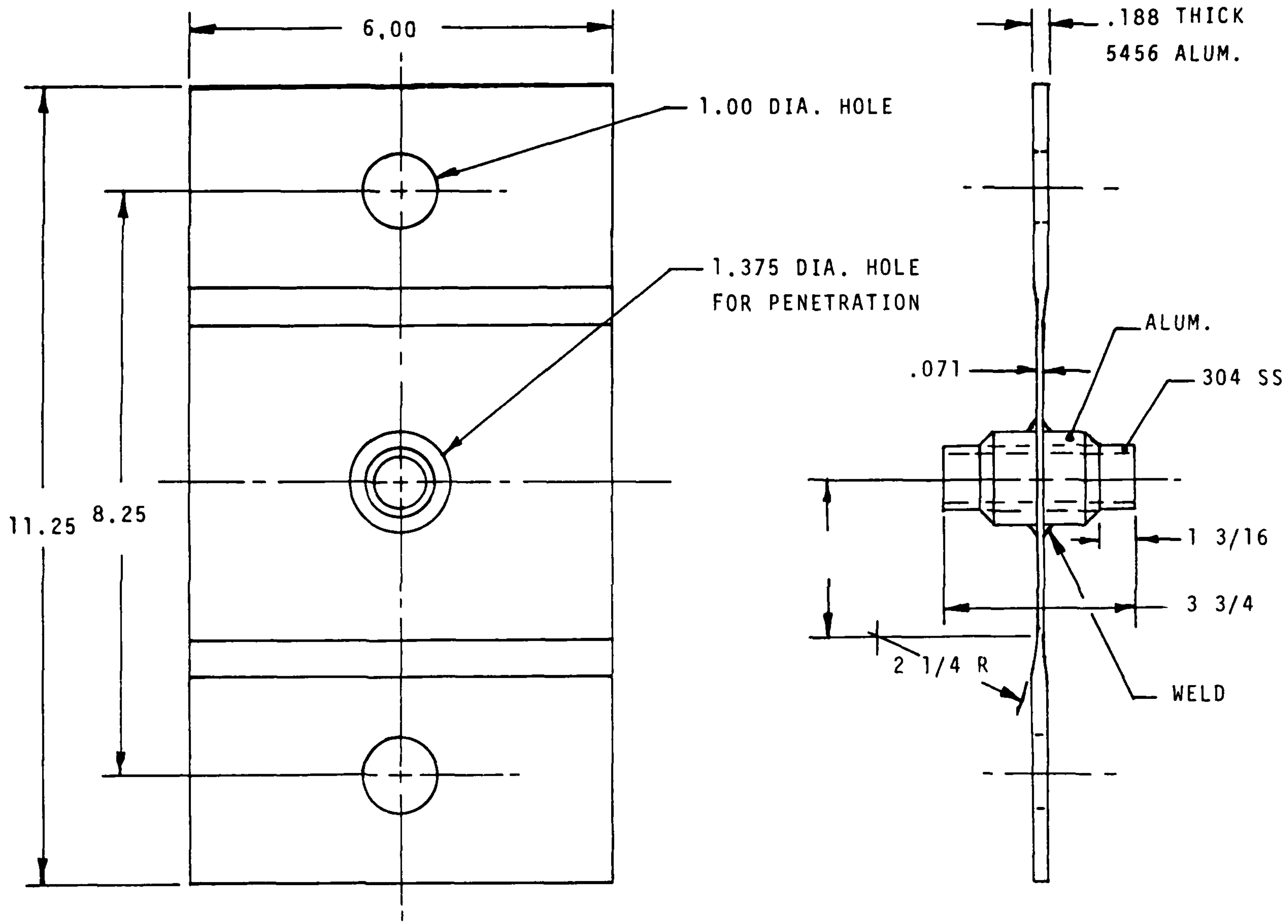


FIGURE 9 HIGH CYCLE FATIGUE EXPLOSIVE BONDED SLEEVE PENETRATION SPECIMEN CONFIGURATION

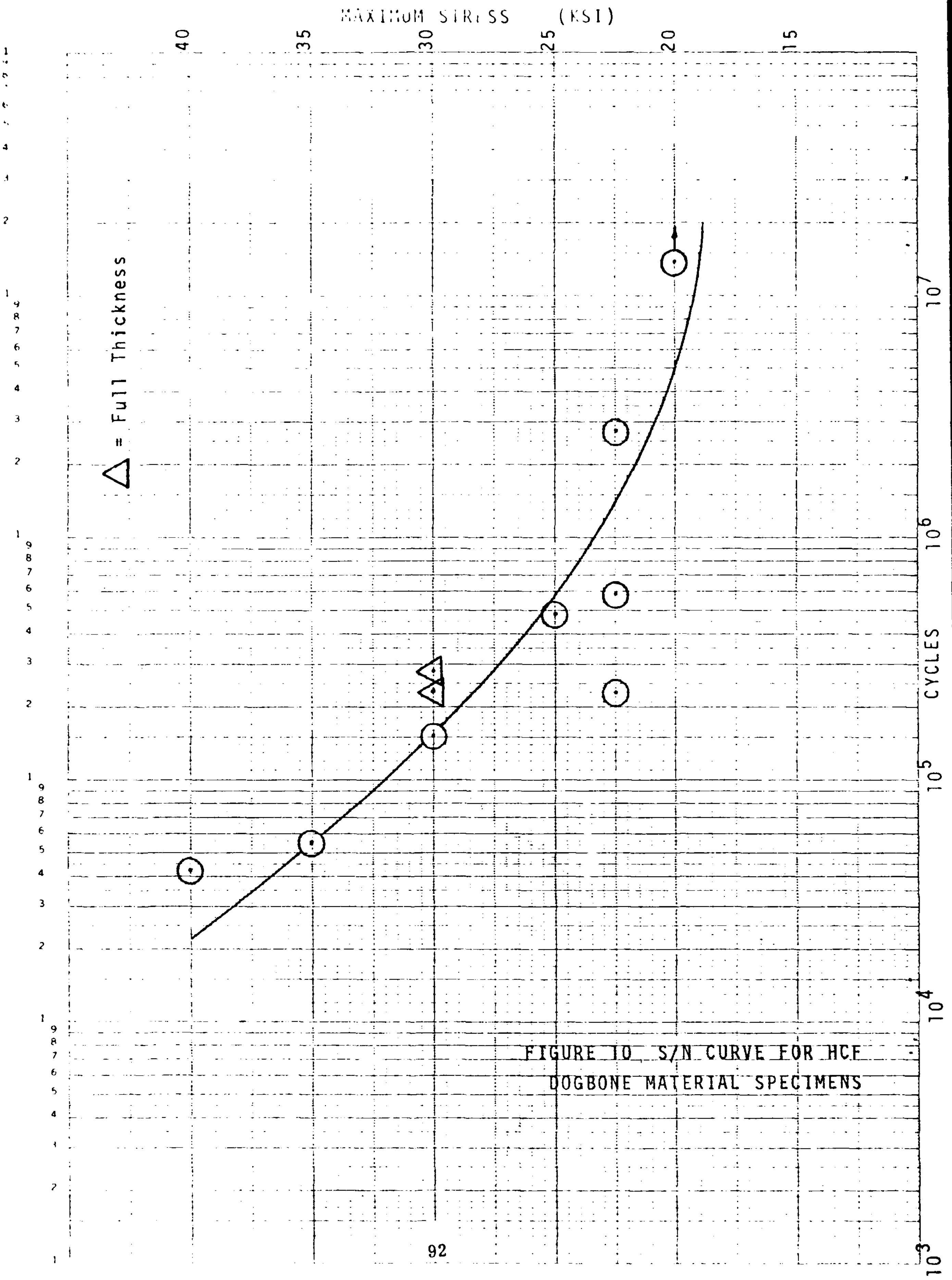


FIGURE 10 S/N CURVE FOR HCF DOGBONE MATERIAL SPECIMENS

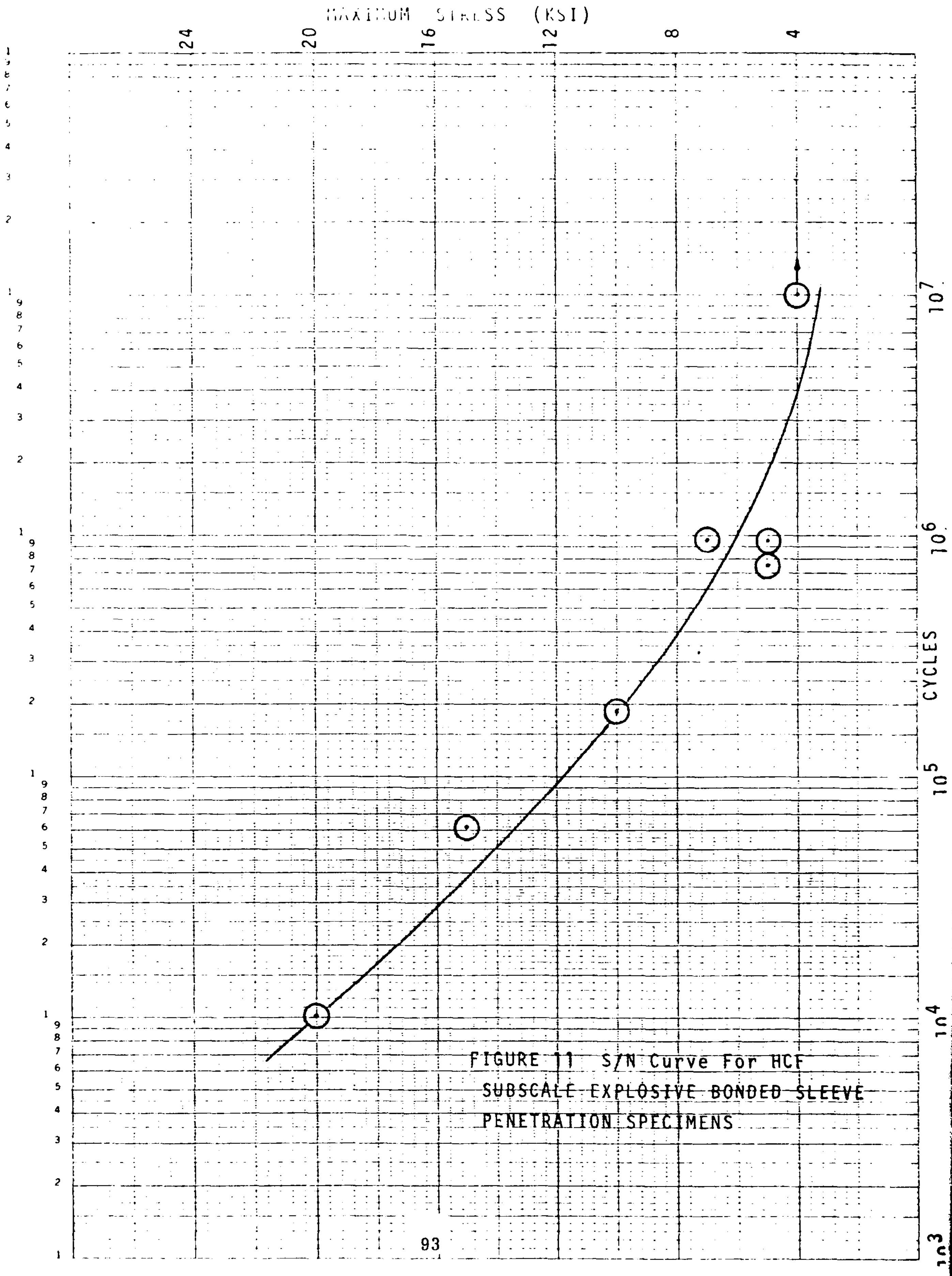


FIGURE 11 S/N Curve For HCF SUBSCALE EXPLOSIVE BONDED SLEEVE PENETRATION SPECIMENS

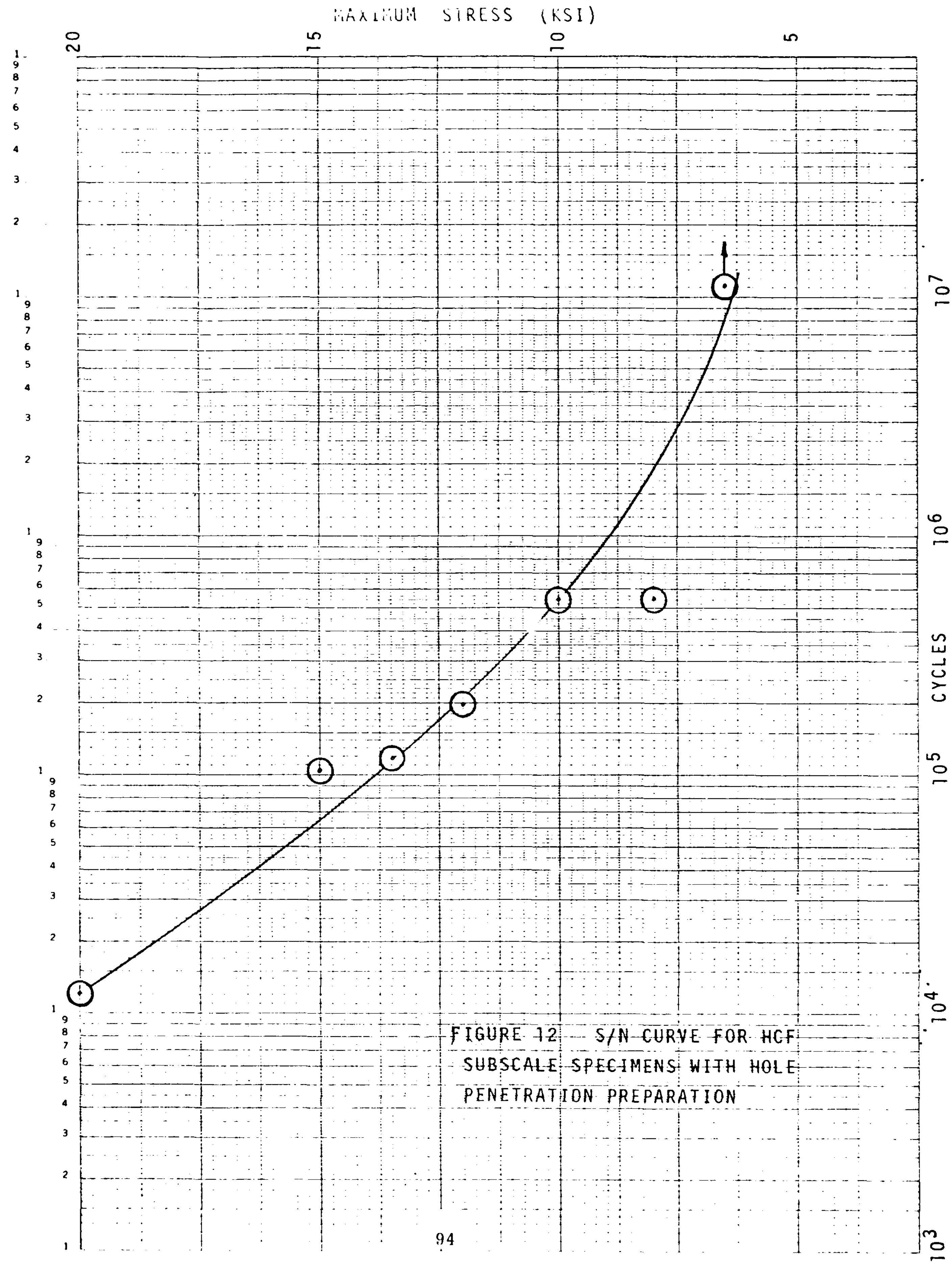


FIGURE 12 S/N CURVE FOR HCF SUBSCALE SPECIMENS WITH HOLE PENETRATION PREPARATION

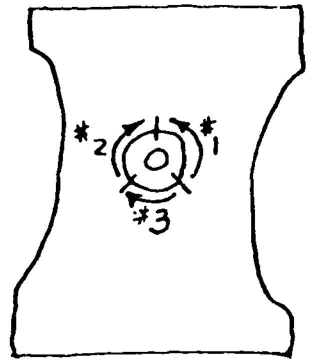
ROHR

ROHR MARINE, INC.

DAILY WELD INFORMATION WORK SHEET

PART NO. PENETRATION
WELDER T. WELCH
STAMP NO. RMW - 41
3-6-75

WELD SEQUENCE



DRAW FILE N/A
WIRE BRUSH YES
CLEAN (SOLVENT) YES (NUMBER)
TACK RUNOFF TAB NO
CLAMP IN POSITION FOR WELD YES
RUN PASS 2 (NUMBER)
BACK CHIP NO
ROTARY FILE START & STOPS
WIRE BRUSH YES
IDENTIFY (STEEL STAMP) NO
INSPECT (QA) YES
GRIND WELD BLEND RUN ONS.

BASE METAL PREPARATION WIRE BRUSH & WIPE WITH SOLVENT
UNIT TYPE AIRCO PA-3A CUP SIZE #10
CURRENT/POLARITY DCRP TORCH NO. HOBART - LINEAR WIRE FEEDER
VOLTAGE: LOW 22 HIGH 24 ACTUAL 23 VOLTAGE PEAK 62
AMPERAGE: LOW 140 HIGH 150 ACTUAL 145 BACKGROUND 25.5
BACKUP BAR: YES ____ NO X TYPE ____
PREHEAT TEMPERATURE N/A INTERPASS TEMPERATURE N/A
GAS FLOW RATE: 30 TO 40 CFH
FILLER WIRE: 5556 3/64 (SIZE) SPOOL NO. ____ LOT NO. ____ FEED (IPM) ____
WELD SPEED: ____ TO MANUAL
ROOT OPENING 0
GAS (IF NOT 75% AR-25% HE) 100% ARGON

PASS SEQUENCE: SEE SKETCH - BOTH SIDES

REMARKS: DCSP TIG TACK WELDED.
FIRST SIDE WELDED FROM OPPOSITE SIDE
OF TACK WELDS.

UNIT PENETRANT EXAMINATION PER NAVSHIPS
0900-003-8000 CL.3 - ACCEPTABLE [signature] 3-4-79

FIGURE 13

RM-143 (1/77)

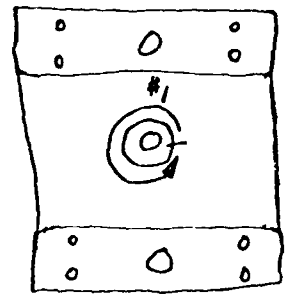
ROHR

ROHR MARINE, INC.

DAILY WELD INFORMATION WORK SHEET

PART NO. PENETRATION
WELDER T. WELCH
STAMP NO. RMW-41
3-7-75

WELD SEQUENCE



DRAW FILE NO
WIRE BRUSH YES
CLEAN (SOLVENT) YES (NUMBER) ____
TACK RUNOFF TAB NO
CLAMP IN POSITION FOR WELD YES
RUN PASS 2 (NUMBER) ____
BACK CHIP NO
ROTARY FILE NO
WIRE BRUSH YES
IDENTIFY (STEEL STAMP) NO
INSPECT (QA) YES
GRIND WELD BLEND RUN ONS.

BASE METAL PREPARATION WIRE BRUSH & WIPE WITH SOLVENT
UNIT TYPE HOBART CYBER-TIG 100 SERIES CUP SIZE #5
CURRENT/POLARITY DCSP TORCH NO. LINDE 3/32 TUNGSTEN
VOLTAGE: LOW ____ HIGH ____ ACTUAL 10 VOLTAGE PEAK ____
AMPERAGE: LOW 100 HIGH 150 ACTUAL 125 BACKGROUND ____
BACKUP BAR: YES ____ NO X TYPE ____
PREHEAT TEMPERATURE NO INTERPASS TEMPERATURE ____
GAS FLOW RATE: 40 TO 60 CFH
FILLER WIRE: 5556 3/64 (SIZE) SPOOL NO. ____ LOT NO. ____ FEED (IPM) ____
WELD SPEED: ____ TO MANUAL
ROOT OPENING 0
GAS (IF NOT 75% AR-25% HE) 100% HELIUM

PASS SEQUENCE: 1 PASS CONTINUOUS BOTH SIDES.

REMARKS: TACK WELDED ONE SIDE - FIRST WELD
OPPOSITE SIDE FROM TACK WELDS
3/16 FILLET

7 UNITS PENETRANT EXAMINATION PER NAVSHIPS
0900-003-8000 CL 3 — ACCEPTABLE 3-9-75

FIGURE 14

RM-143 (1/77)

TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

REPORT NO. TH-3193

TABLE I

LOW CYCLE FATIGUE

Maximum Stress (KSI) 13.5 (41,810 Lbs.)
Minimum Stress (KSI) 0.5 (1,549 Lbs.)
Frequency: 2.0 Hz

Specimen No. 1 WITHOUT PENETRATION PREPARATION

STRAIN-MICROINCHES PER INCH (@ 13.5 KSI)

	STRAIN GAGE NUMBER							
Cycles	1	2	3	4	5	6	7	8
0	1325	1320	1300	1300	1300	1305	1265	1295
5,000	1325	1330	1300	1285	1305	1305	1265	1290
10,000	1320	1325	1310	1290	1300	1305	1280	1295
20,000	1325	1330	1315	1295	1305	1310	1285	1310
50,000	1320	1325	1320	1300	1300	1315	1275	1320
100,000	1320	1330	1320	1305	1300	1315	1290	1315
150,000	1320	1335	1325	1320	1305	1320	1295	1325
200,000	1325	1330	1325	1325	1310	1325	1295	1315
250,000	1325	1335	1320	1320	1310	1325	1295	1320
300,000	1320	1330	1325	1315	1305	1320	1295	1320
350,000	1320	1330	1315	1305	1300	1315	1290	1300
400,000	1320	1330	1315	1300	1300	1290	1295	1290
450,000	1320	1330	1305	1290	1300	1300	1290	1295
500,000	1315	1330	1310	1295	1295	1295	1280	1295
550,000	1315	1325	1305	1280	1290	1290	1285	1305
600,000	1310	1325	1310	1290	1295	1290	1285	1305
650,000	1310	1330	1315	1295	1290	1300	1280	1310
700,000	1315	1330	1310	1300	1295	1305	1280	1310
750,000	1315	1340	1325	1300	1300	1315	1270	1315

TABLE I

LOW CYCLE FATIGUE (CONT'D.)

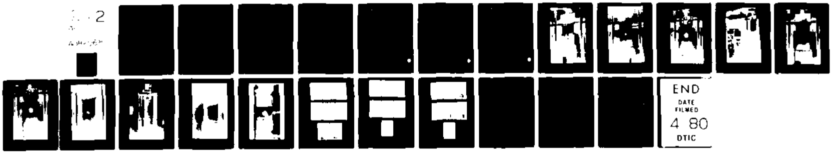
Specimen No. 1

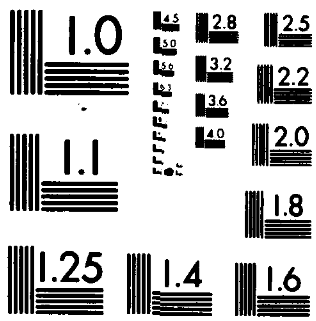
	STRAIN GAGE NUMBER							
Cycles	1	2	3	4	5	6	7	8
800,000	1315	1340	1330	1300	1300	1315	1275	1315
850,000	1315	1345	1325	1300	1300	1310	1270	1325
900,000	1320	1350	1330	1300	1300	1310	1270	1330
950,000	1320	1340	1320	1300	1295	1310	1270	1305
1,000,000	1320	1335	1320	1290	1290	1310	1270	1300

REMARKS

No visible cracks were observed for the duration of the test.

AD-A082 068 NAVAL ORDNANCE STATION LOUISVILLE KY MFG TECHNOLOGY --ETC F/G 13/8
EXPLOSIVELY JOINING DISSIMILAR METAL TUBES.(U)
NOV 79 T R MARSHALL
UNCLASSIFIED NOSL-MT-053 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

REPORT NO. TH-3193

TABLE II

LOW CYCLE FATIGUE

Maximum Stress (KSI) 13.5 (41,702 Lbs.)
Minimum Stress (KSI) 0.5 (1,545 Lbs.)
Frequency: 2.0 Hz

Specimen No. 2 WITH PENETRATION PREPARATION (2 7/8" Dia. Hole in Center)

STRAIN-MICROINCHES PER INCH (@ 13.5 KSI)

	STRAIN GAGE NUMBER								
Cycles	1	2	3	4	5	6	7	8	9
0	300	1370	1325	290	2050	1350	1190	1400	4470
100	280	1360	1330	290	2015	1340	1195	1410	4225
5,000	285	1370	1340	290	2020	1345	1190	1410	4240
10,000	280	1365	1340	290	2020	1340	1190	1415	4240
20,000	290	1365	1340	270	2020	1340	1195	1425	4245
50,000	270	1345	1325	270	2015	1340	1180	1415	4220
100,000	300	1345	1330	270	2020	1345	1185	1415	4610
141,790		(FAILURE)							

REMARKS

No visible cracks were observed after 100, 5,000, 10,000, 20,000, 50,000 and 100,000 cycles.

TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

REPORT NO. TH-3193

TABLE III

LOW CYCLE FATIGUE

Maximum Stress (KSI) 13.5 (41,378 Lbs.)
Minimum Stress (KSI) 0.5 (1,533 Lbs.)
Frequency: 2.0 Hz

Specimen No. 3 WITH BOLTED FLANGE PENETRATION

STRAIN-MICROINCHES PER INCH (@ 13.5 KSI)

	STRAIN GAGE NUMBER									
Cycles	1	2	3	4	5	6	7	8	9	10
0	700	725	1340	1410	1795	3590	3550	1460	1490	940
100	700	740	1320	1360	1630	3575	3525	1415	1460	1160
5,000	700	740	1330	1350	1550	3550	3520	1415	1440	1140
10,000	715	750	1330	1360	1560	3575	3530	1395	1445	1200
20,000	705	730	1330	1365	1560	3550	3520	1405	1435	1160
50,000	710	735	1340	1360	1570	3560	3170	1410	1440	1140
80,680		(FAILURE)								

REMARKS

No visible cracks were observed after
100, 5,000, 10,000, 20,000, and
50,000 cycles.

TABLE IV

LOW CYCLE FATIGUE

Maximum Stress (KSI) 13.5 (41,756 Lbs.)
Minimum Stress (KSI) 0.5 (1,547 Lbs.)
Frequency: 2.0 Hz

Specimen No. 4 WITH EXPLOSIVE BONDED SLEEVE PENETRATION

STRAIN-MICROINCHES PER INCH (@ 13.5 KSI)

	STRAIN GAGE NUMBER							
Cycles	1	2	3	4	5	6	7	8
0	1940	1340	1580	960	1555	1565	1350	1530
5,000	1630	1070	1500	1085	1510	1050	1365	1415
10,000	1625	1070	1505	1090	1515	1050	1365	1415
20,000	1605	1070	1490	1095	1495	1045	1365	1400
50,000	1530	1055	1510	1095	1530	1060	1370	1410

REMARKS

0	No visible cracks were observed
5,000	" " " " "
10,000	" " " " "
20,000	" " " " "
50,000	" " " " "
81,790	Crack observed on one face of penetration @ weld
84,260	Crack has extended across the top of weld
88,840	Crack observed on opposite face of penetration @ weld
96,860	Failure

TABLE V

STEP LOADED STEADY STATE STRAIN DATA

Specimen No. 4 WITH EXPLOSIVE BONDED SLEEVE PENETRATION

STRAIN-MICROINCHES PER INCH

LOAD LBS.	STRAIN GAGE NUMBER 1	2	3	4	5	6	7	8
500	30	-5	15	-10	15	5	0	0
1000	180	-70	105	-85	95	40	50	50
2000	275	-85	175	-100	160	70	90	90
3000	355	-80	230	-110	210	95	120	130
4000	420	-70	280	-100	260	120	155	175
5000	475	-55	325	-90	300	145	190	215
6000	525	-35	370	-75	335	175	220	260
7000	570	-10	405	-55	375	200	255	295
8000	620	15	440	-30	410	225	295	340
9000	655	40	480	0	450	250	325	380
10,000	705	65	515	10	485	280	355	415
20,000	1095	365	855	290	825	575	690	780
30,000	1480	740	1185	595	1160	980	1000	1130
41,756	1940	1340	1580	960	1555	1565	1350	1530

NOTE: These strain data reflect the result of warpage in the panel caused during welding of sleeve penetration.

TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

REPORT NO. TH-3193

TABLE VI

HIGH CYCLE
FATIGUE

CUSTOMER: Naval Ordnance Station

Date: May, 1979

Material: 5456 Aluminum-Plate

R Ratio: .037

Type Test: Axial Tension-Tension

Pre-Conditioning: As received

Frequency: 1800 CPM

Test Condition: 23° C

Specimen Type: Dog bone

Test Equipment: Satec SF-1U-1099

Specimen (No.)	Max. Stress (KSI)	Static Stress (KSI)	Dynamic Stress (KSI)	Failure Cycles x 10^3	Width (in.)	Thickness (in.)	Remarks
1	40.00	20.74	19.26	42	1.000	.068	No visible cracks
2	35.00	18.15	16.85	55	1.000	.069	No visible cracks
3	30.00	15.56	14.44	152	1.000	.069	No visible cracks
4	25.00	12.96	12.04	482	1.001	.070	No visible cracks
5	20.00	10.37	9.63	**13,770	0.999	.070	No visible cracks
6	22.50	11.67	10.83	589	1.002	.069	No visible cracks
7	22.50	11.67	10.83	229	1.000	.071	No visible cracks
8	22.50	11.67	10.83	2,738	1.000	.070	No visible cracks
* 9	30.00	15.56	14.44	280	1.001	.193	No visible cracks
* 10	30.00	15.56	14.44	230	0.997	.194	No visible cracks

*full thickness

**run out - no failure

Respectfully Submitted

CINCINNATI TESTING LABORATORIES, INC.
417 NORTHLAND ROAD
CINCINNATI, OHIO 45240

Test Technician: D. Browning
D. Browning

Approved: G. A. Huber
G. A. Huber

TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

REPORT NO. TH-3193

TABLE VII

HIGH CYCLE

FATIGUE

CUSTOMER: Naval Ordnance Station

Date: May, 1979

Material: 5456 Aluminum-Plate

R Ratio: .037

Type Test: Axial Tension-Tension

Pre Conditioning: As received

Frequency: 1800 CPM

Test Condition: 23° C

Specimen Type: 3/4" I.P.S. explosive bonded penetrations

Test Equipment: Satec SF-1U-1099

Specimen (No.)	Max. Stress (KSI)	Static Stress (KSI)	Dynamic Stress (KSI)	Failure Cycles x 10^3	Width (in.)	Thickness (in.)	Remarks
1	20.00	10.37	9.63	10	6.000	.070	Crack @ 5,000 cycles
2	15.00	7.78	7.22	61	5.996	.072	Crack @ 46,000 cycles
3	10.00	5.19	4.81	186	6.000	.072	Crack @ 146,000 cycles
4	7.00	3.63	3.37	950	6.000	.072	Crack @ 850,000 cycles
5	5.00	2.59	2.41	951	5.993	.073	Crack @ 587,000 cycles
6	4.00	2.07	1.93	*10,012	5.998	.074	Hairline crack @ 0 cycles
7	5.00	2.59	2.41	748	6.000	.071	Hairline crack @ 0 cycles
8							
9							
10							

*run out - no failure

Respectfully Submitted

CINCINNATI TESTING LABORATORIES, INC.
417 NORTHLAND ROAD
CINCINNATI, OHIO 45240

Test Technician: D. Browning
D. Browning

Approved: G. A. Huber
G. A. Huber

TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

REPORT NO. TH-3193

TABLE VIII

HIGH CYCLE

FATIGUE

CUSTOMER: Naval Ordnance Station

Material: 5456 Aluminum-Plate

Type Test: Axial Tension-Tension

Frequency: 1800 CPM

Specimen Type: With Penetration Preparation (1 1/2" circular hole in center of gage section)

Date: May, 1979

R Ratio: .037

Pre Conditioning: As received

Test Condition: 23° C

Test Equipment: Satec SF-1U-1099

Specimen (No.)	Max. Stress (KSI)	Static Stress (KSI)	Dynamic Stress (KSI)	Failure Cycles x 10^3	Width (in.)	Thickness (in.)	Remarks
1	20.00	10.37	9.63	12	6.003	.072	No visible cracks
2	15.00	7.78	7.22	103	6.005	.074	Crack @ 100,000 cycles
3	13.50	7.00	6.50	117	6.003	.073	Crack @ 99,000 cycles
4	12.00	6.22	5.78	196	6.003	.073	Crack @ 133,000 cycles
5	10.00	5.19	4.81	543	6.003	.073	Crack @ 487,000 cycles
6	8.00	4.15	3.85	543	6.003	.073	Crack @ 489,000 cycles
7	6.50	3.37	3.13	*11,325	6.003	.072	No visible cracks
8							
9							
10							

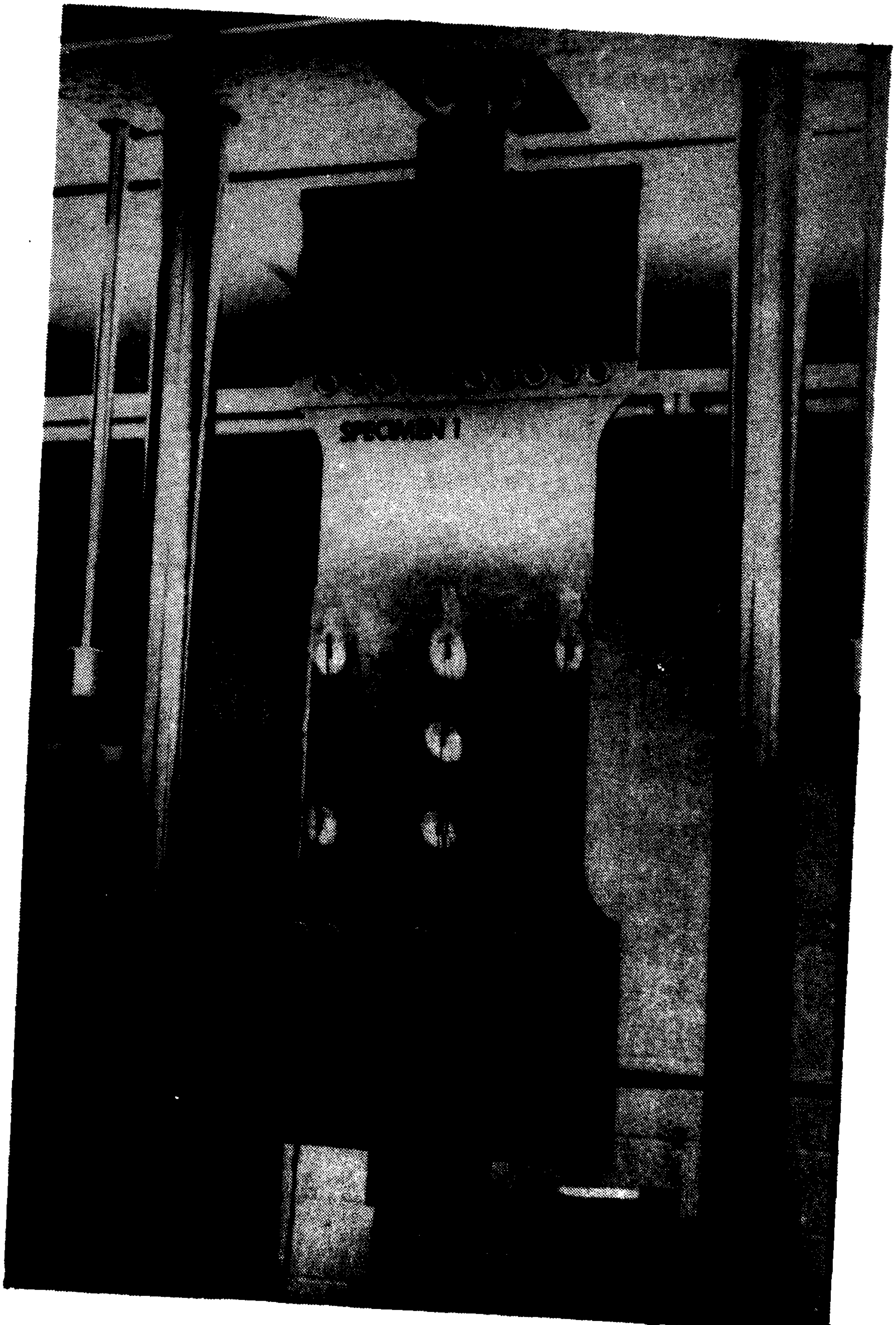
*run out - no failure

Respectfully Submitted

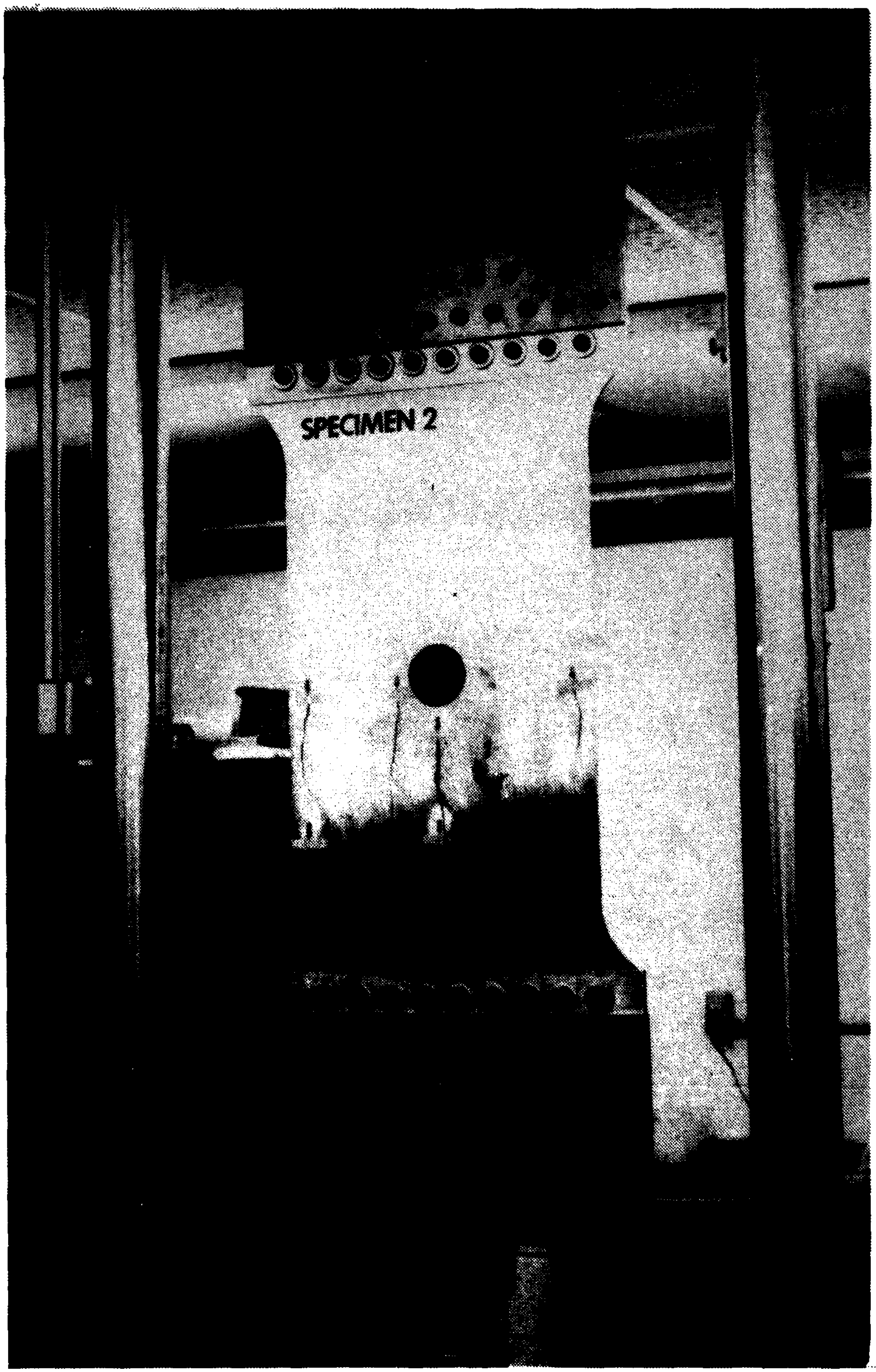
CINCINNATI TESTING LABORATORIES, INC.
417 NORTHLAND ROAD
CINCINNATI, OHIO 45240

Test Technician: D. Browning D. Browning

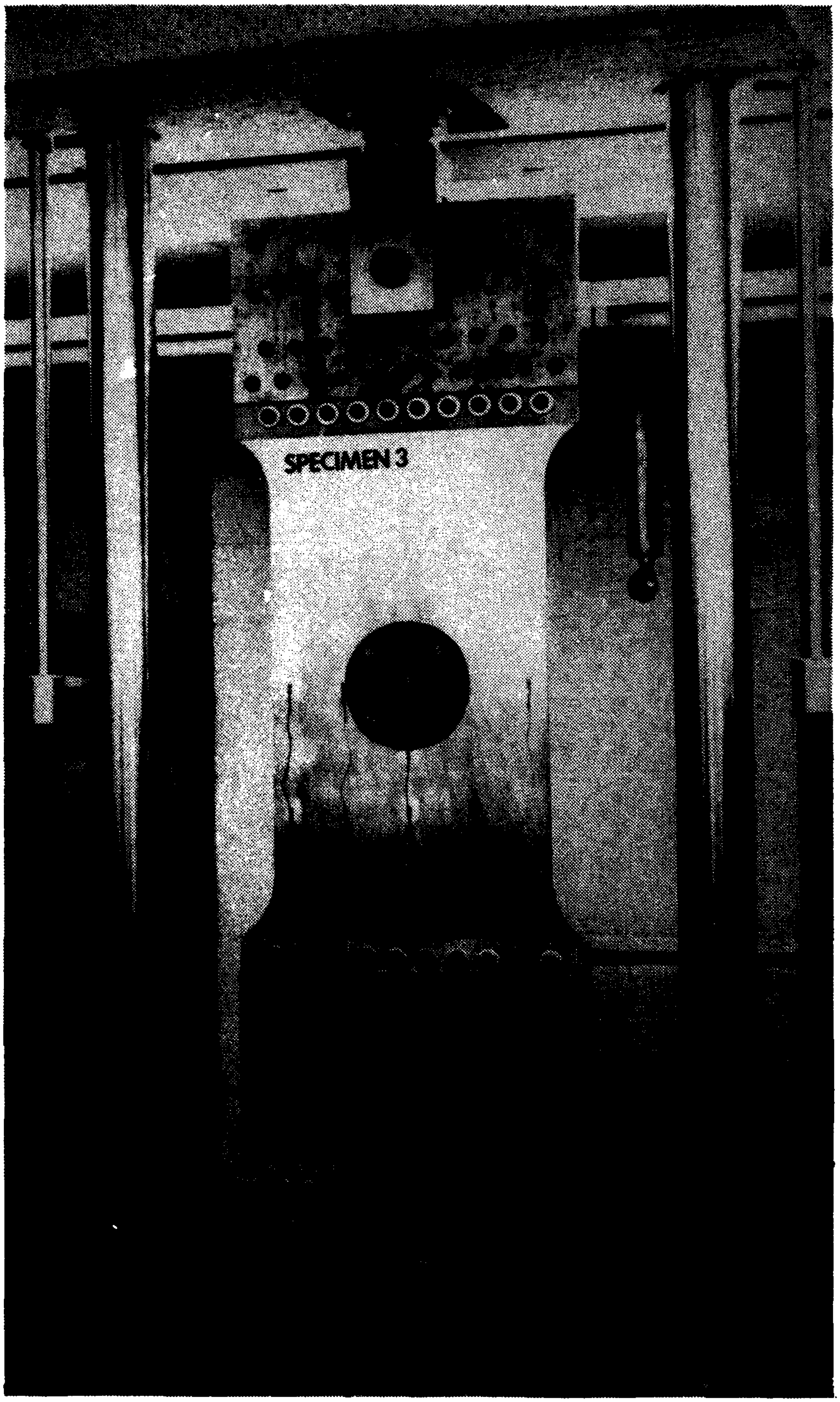
Approved: G. A. Huber G. A. Huber



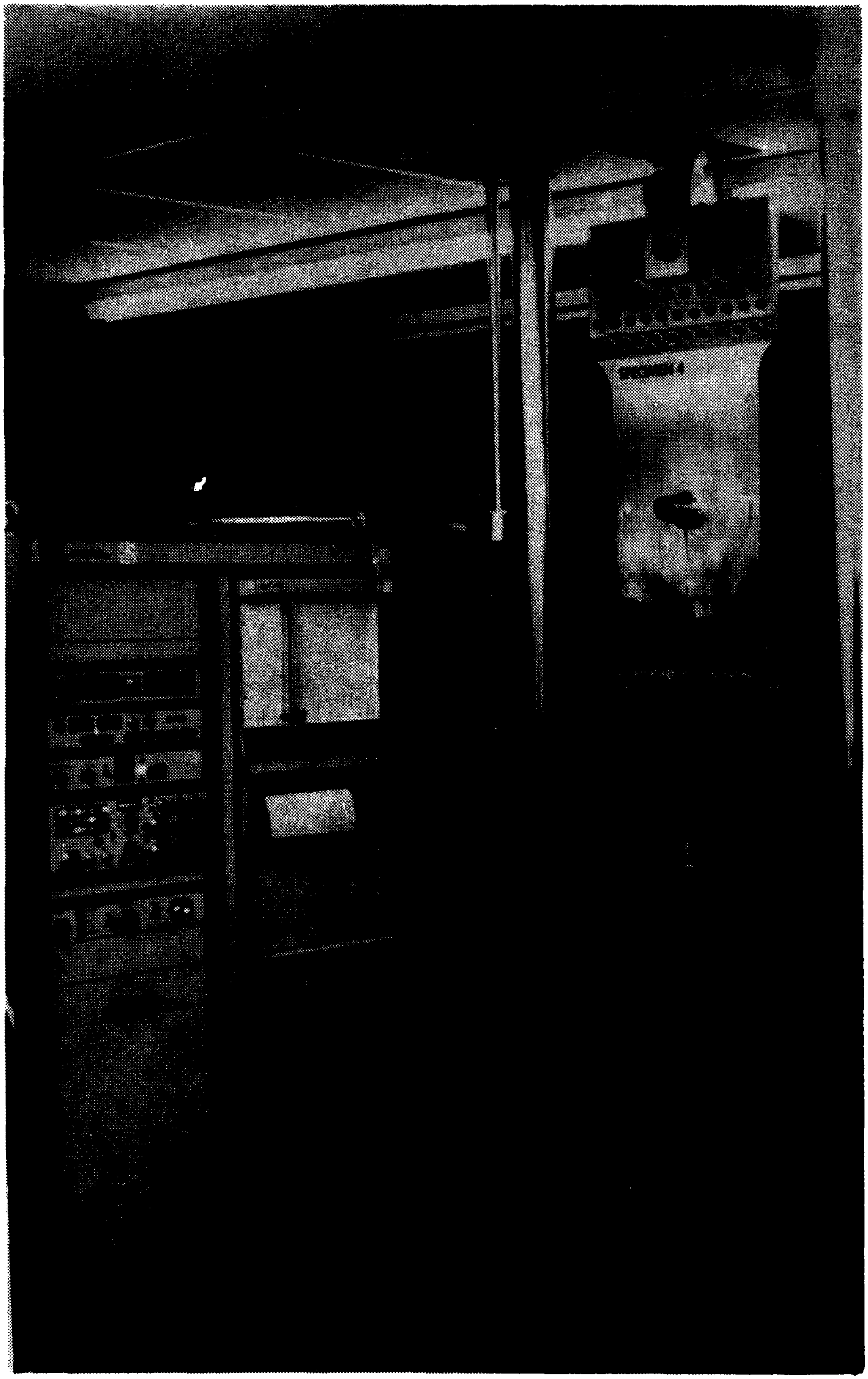
PHOTOGRAPH 1
PANEL SPECIMEN WITHOUT
PENETRATION PREPARATION



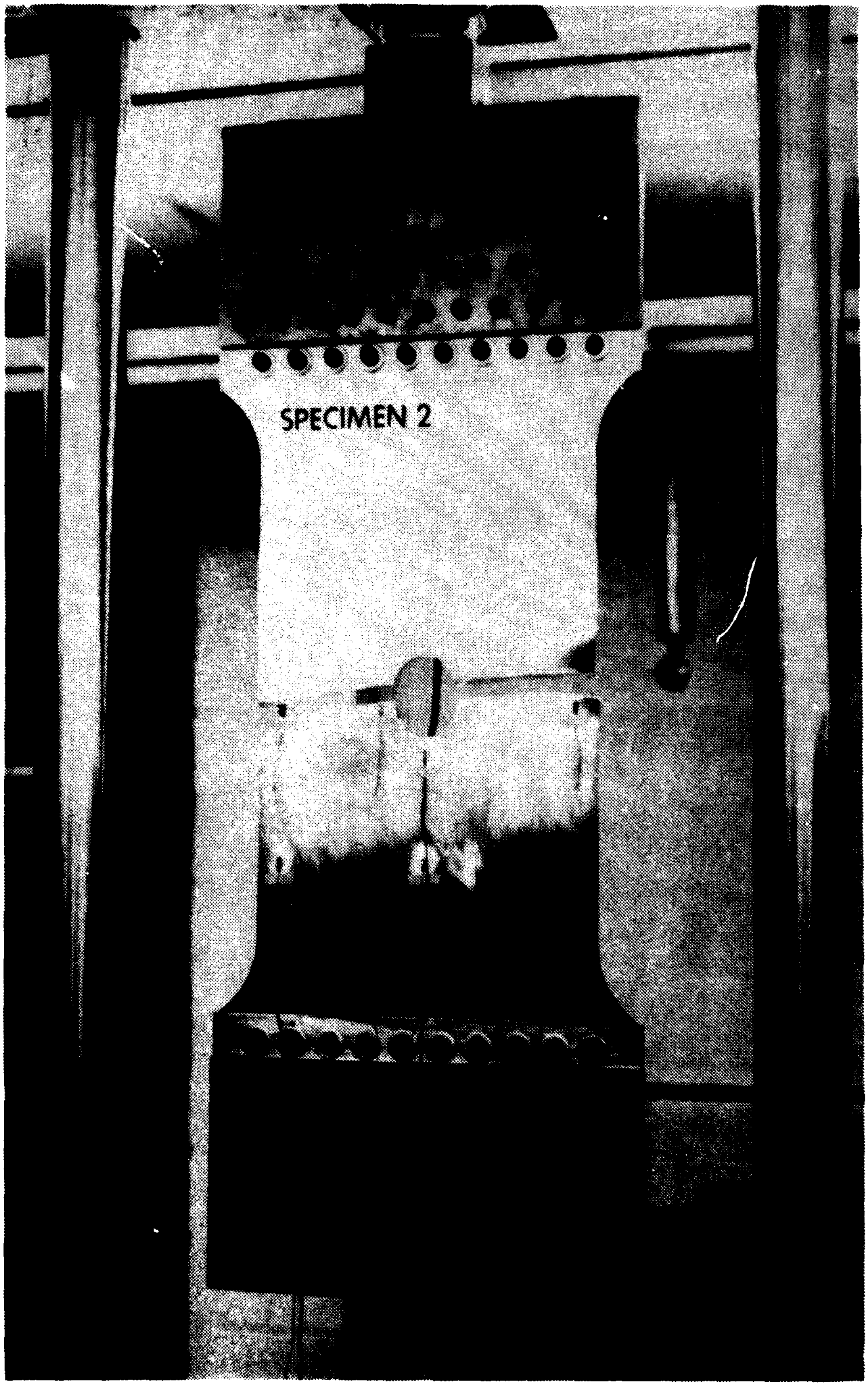
PHOTOGRAPH 2
PANEL SPECIMEN WITH HOLE PENETRATION
PREPARATION BEFORE TEST



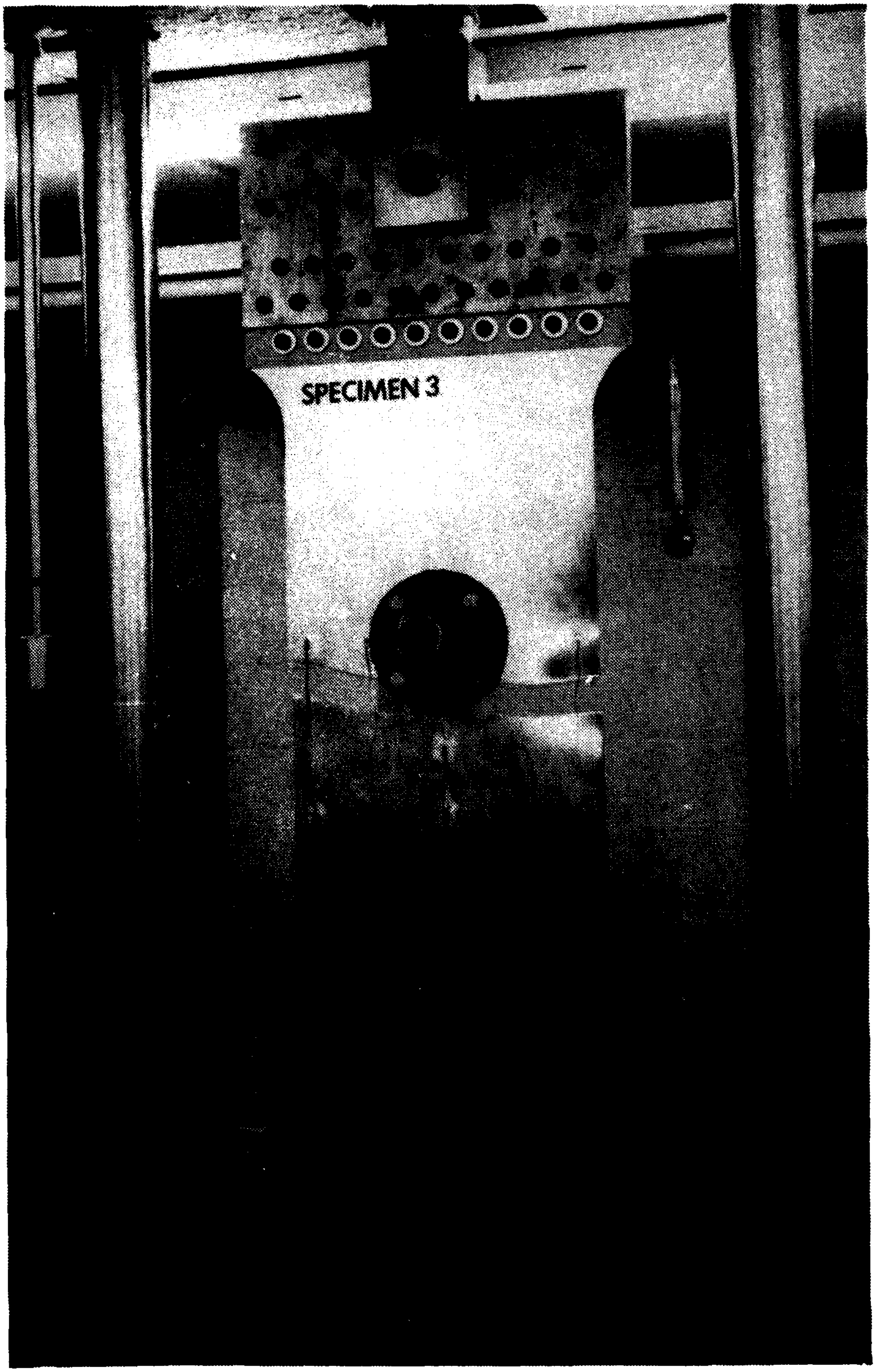
PHOTOGRAPH 3
PANEL SPECIMEN WITH BOLTED FLANGE
PENETRATION BEFORE TEST



PHOTOGRAPH 4
PANEL SPECIMEN WITH EXPLOSIVE BONDED
SLEEVE PENETRATION BEFORE TEST

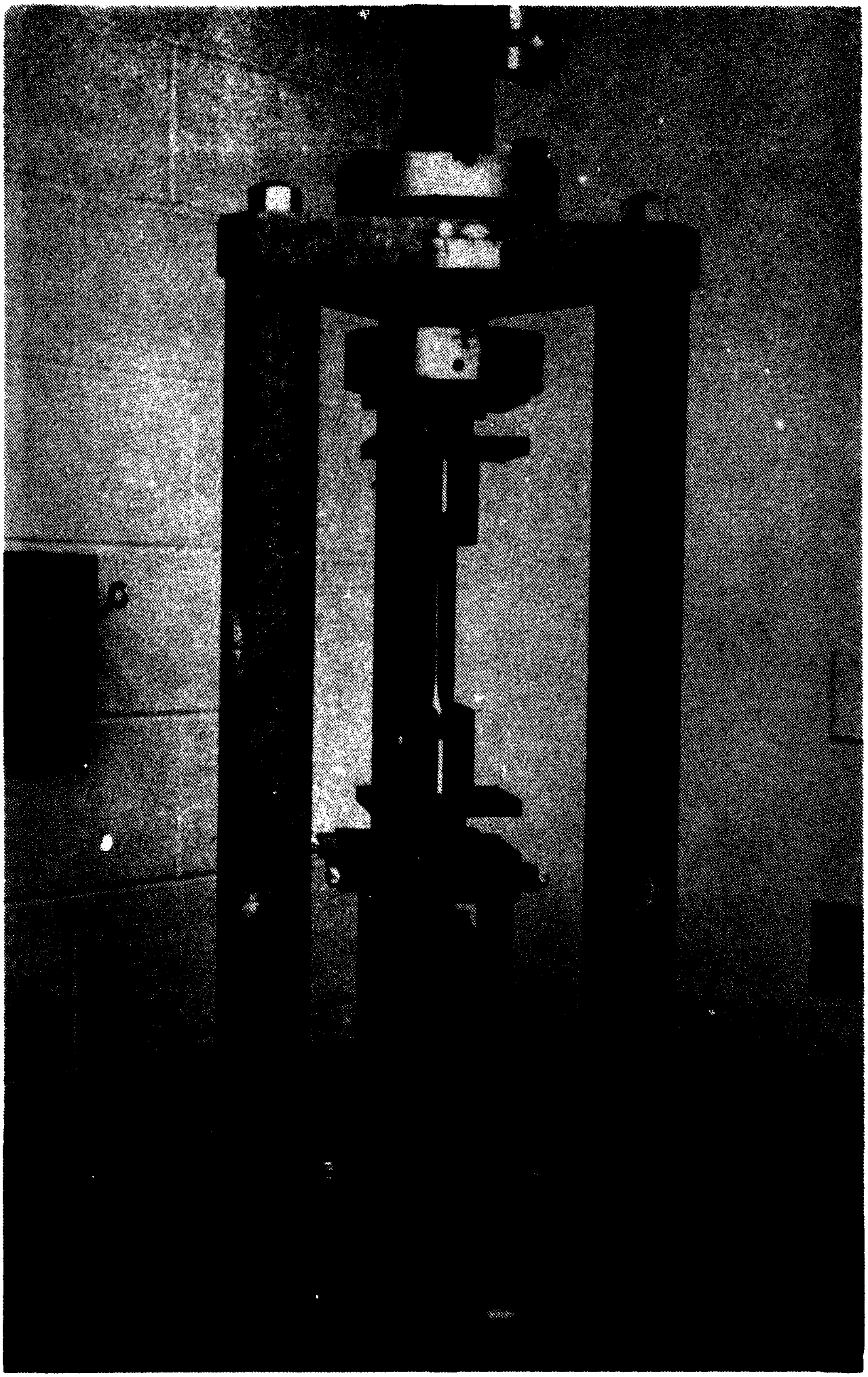


PHOTOGRAPH 5
PANEL SPECIMEN WITH HOLE PENETRATION
PREPARATION AFTER TEST

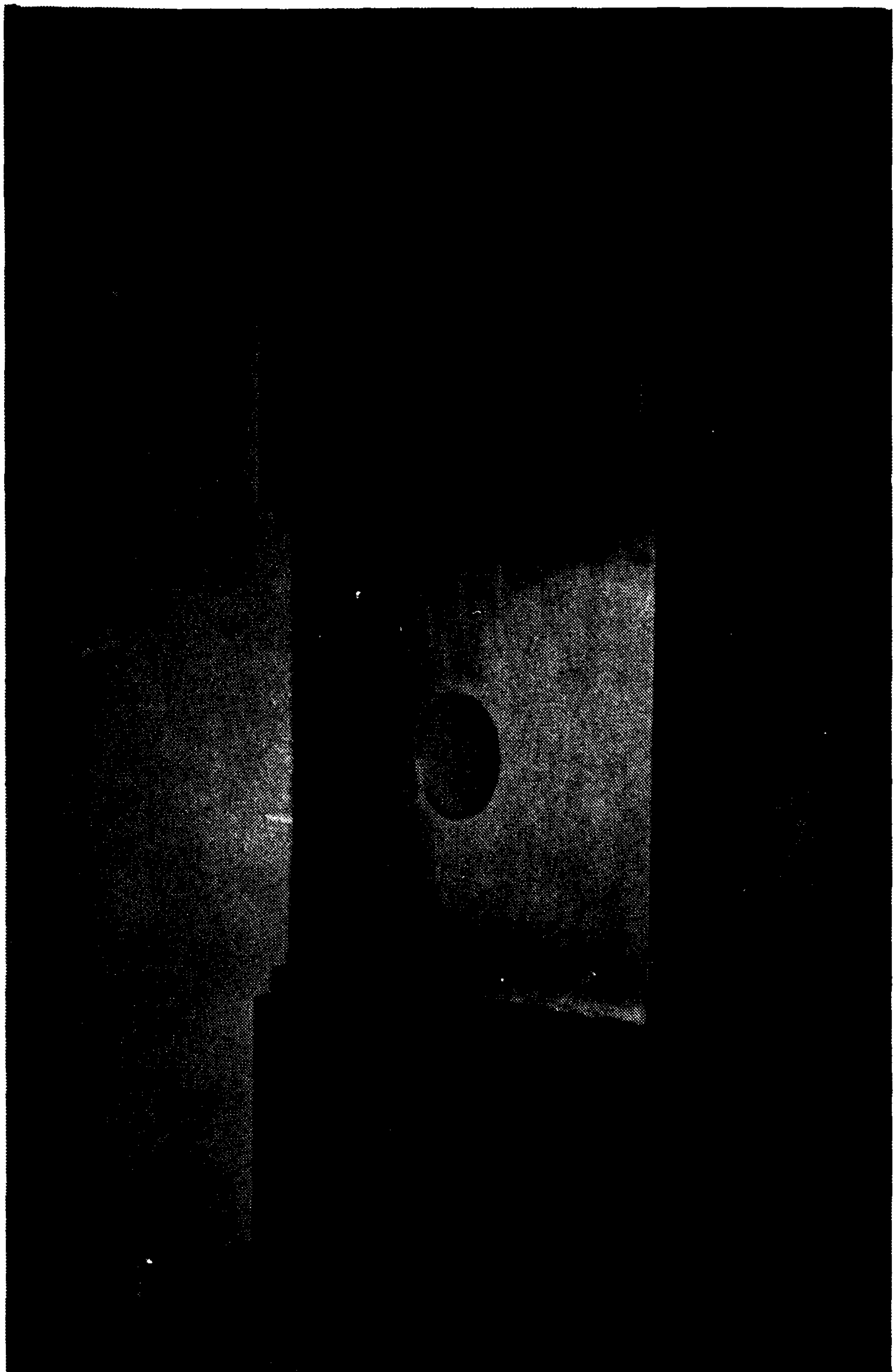


PHOTOGRAPH 6
PANEL SPECIMEN WITH BOLTED FLANGE
PENETRATION AFTER TEST

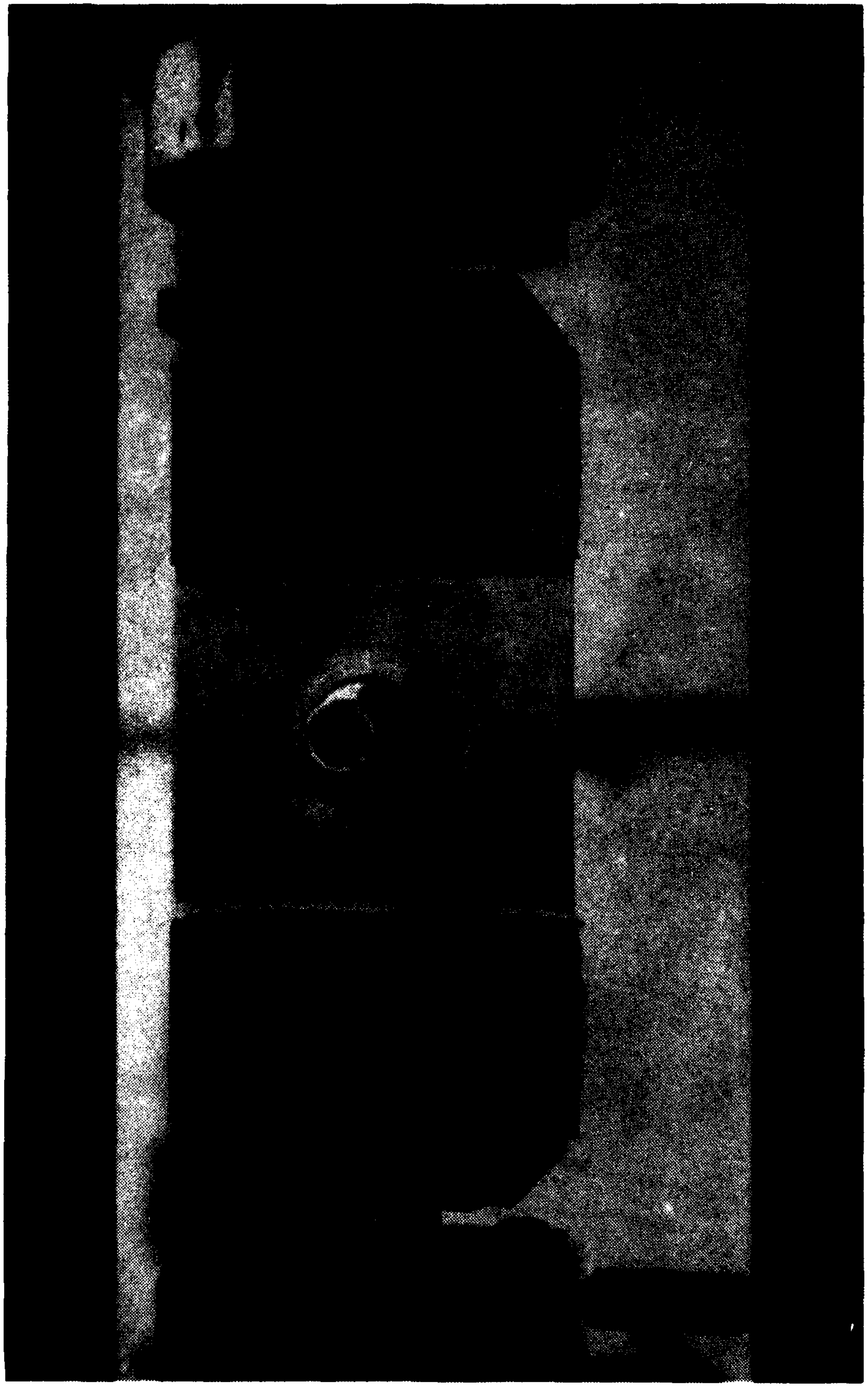
PHOTOGRAPH 7
PANEL SPECIMEN WITH EXPLOSIVE BONDED
SLEEVE PENETRATION AFTER TEST



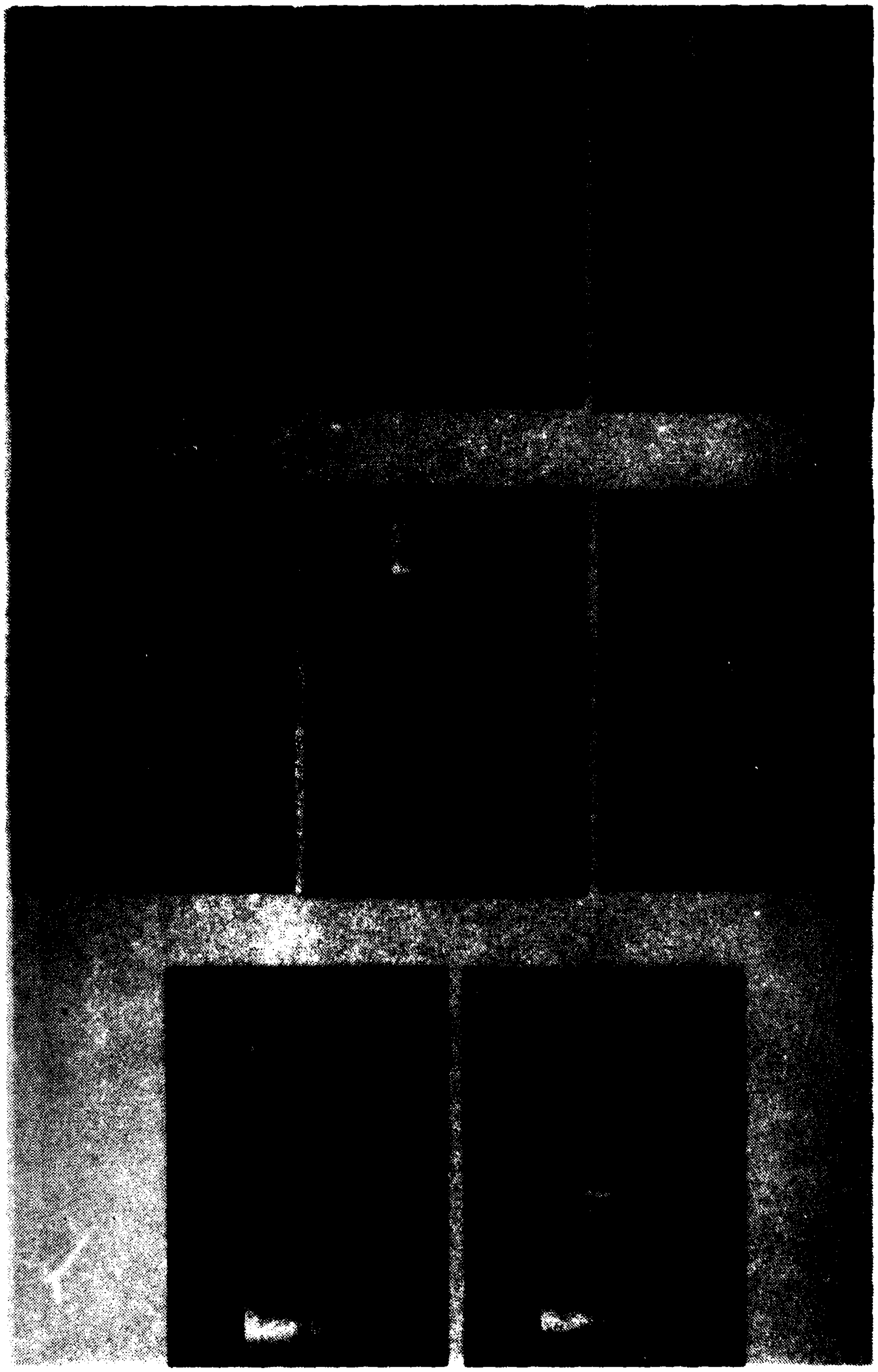
PHOTOGRAPH 8
HCF SUBSCALE DOGBONE SPECIMEN SET-UP FOR TEST



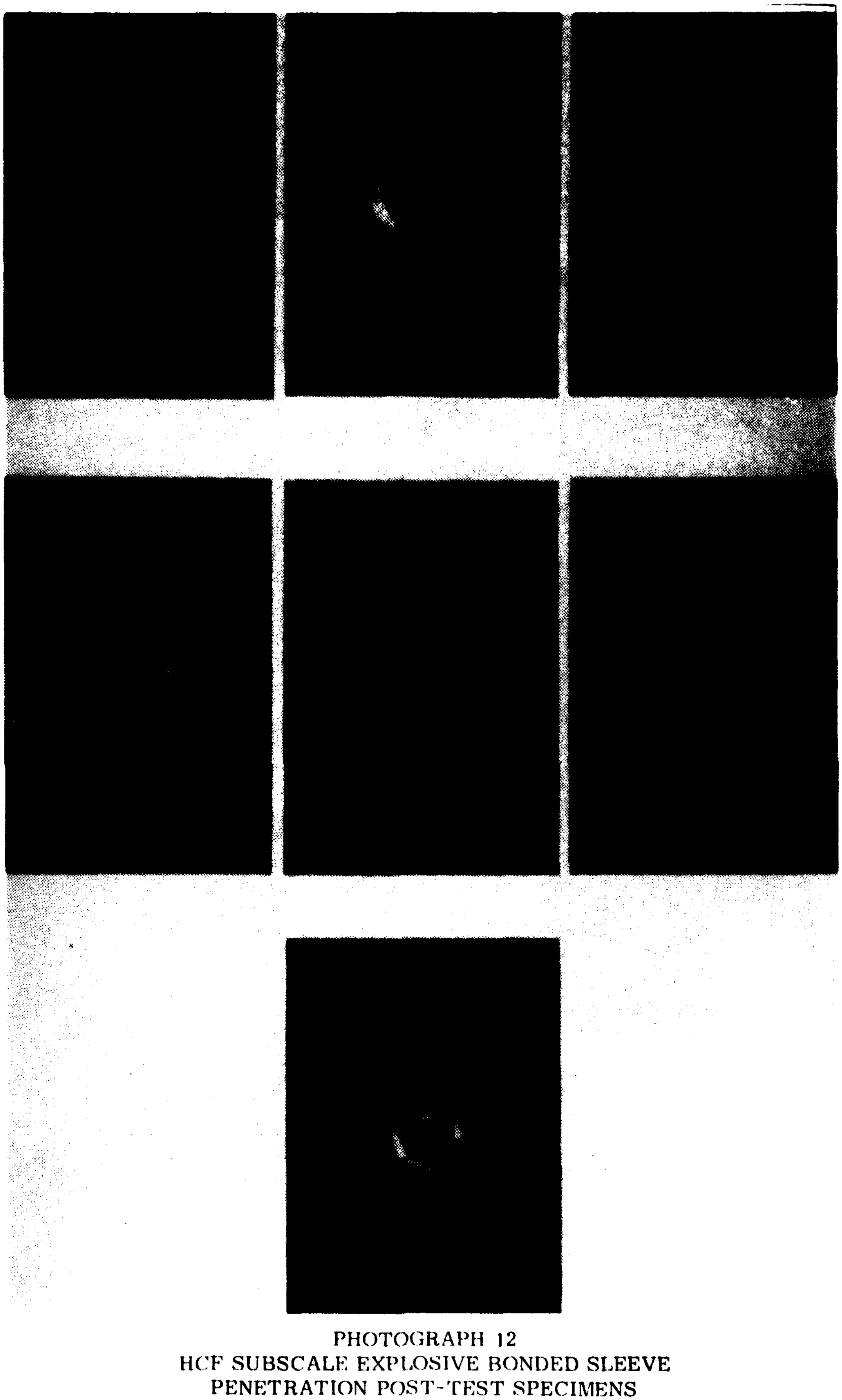
PHOTOGRAPH 9
HCF SUBSCALE SPECIMEN WITH HOLE SET-UP FOR TEST



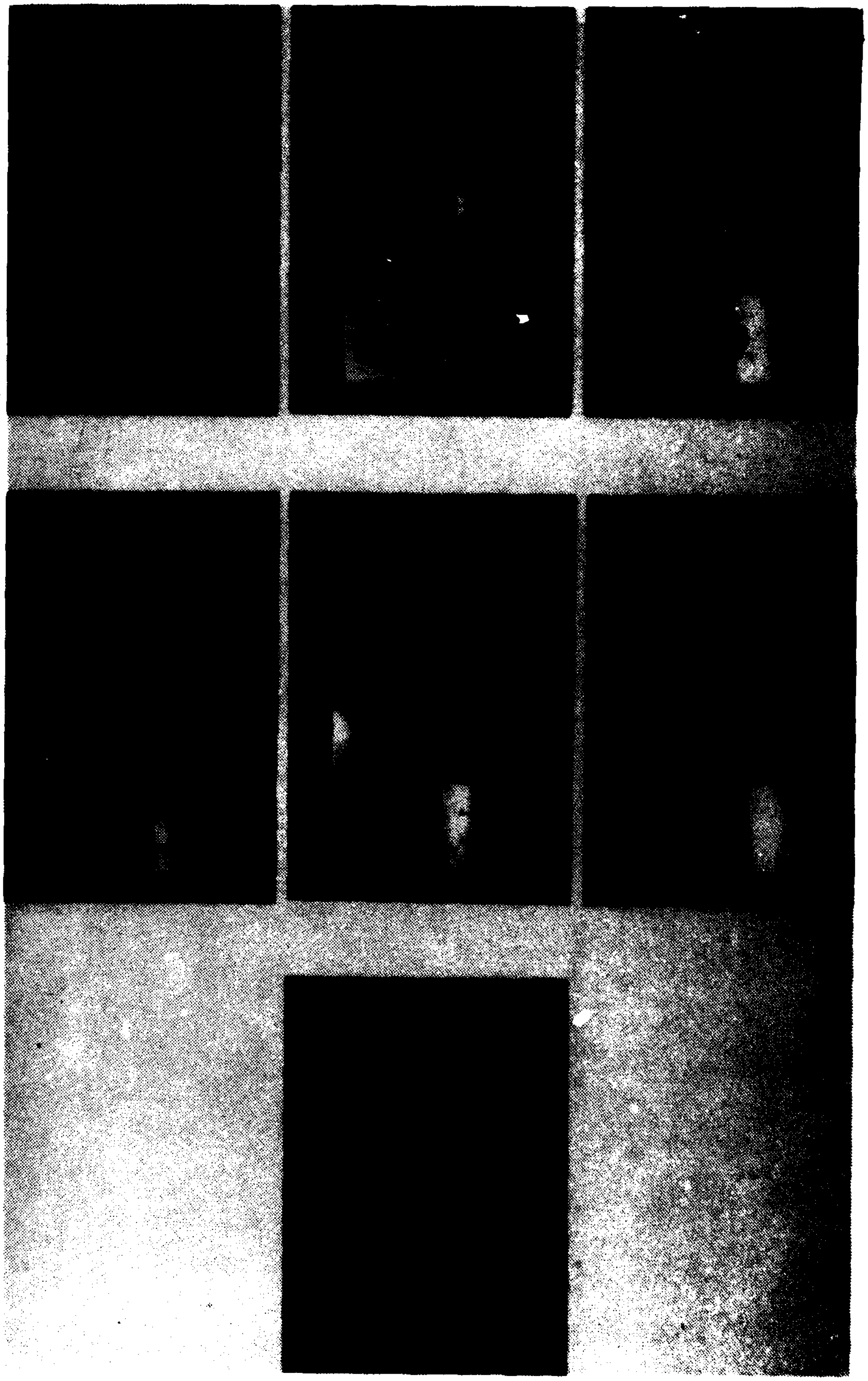
PHOTOGRAPH 10
HCF SUBSCALE EXPLOSIVE BONDED
PENETRATION SET-UP FOR TEST



PHOTOGRAPH 11
HCF DOGBONE POST-TEST SPECIMENS



PHOTOGRAPH 12
HCF SUBSCALE EXPLOSIVE BONDED SLEEVE
PENETRATION POST-TEST SPECIMENS



PHOTOGRAPH 13
HCF SUBSCALE POST-TEST SPECIMENS
WITH HOLE PENETRATION PREPARATION

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Explosive Cladding
Dissimilar Metals
Watertight Integrity
Bulkhead/Deck Penetration
Surface Effect Ships (SES)

3/4 in. to 6 in.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This project was conducted to further develop the explosive cladding process and to use this process by joining pipes/tubes of metals that cannot be welded together by conventional methods. The project was diverted from the original plan to utilize a "scarf-joint" transition joint of identical size pipes/tubes to development of a method of penetrating watertight bulkheads or decks with a pipe/tube having widely different properties. The emphasis was on penetrating aluminum bulkheads/decks with stainless steel pipes of sizes from 3/4" to 6" for Surface Effect Ship application.

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